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PIONEERS OF BRITISH INDUSTRY

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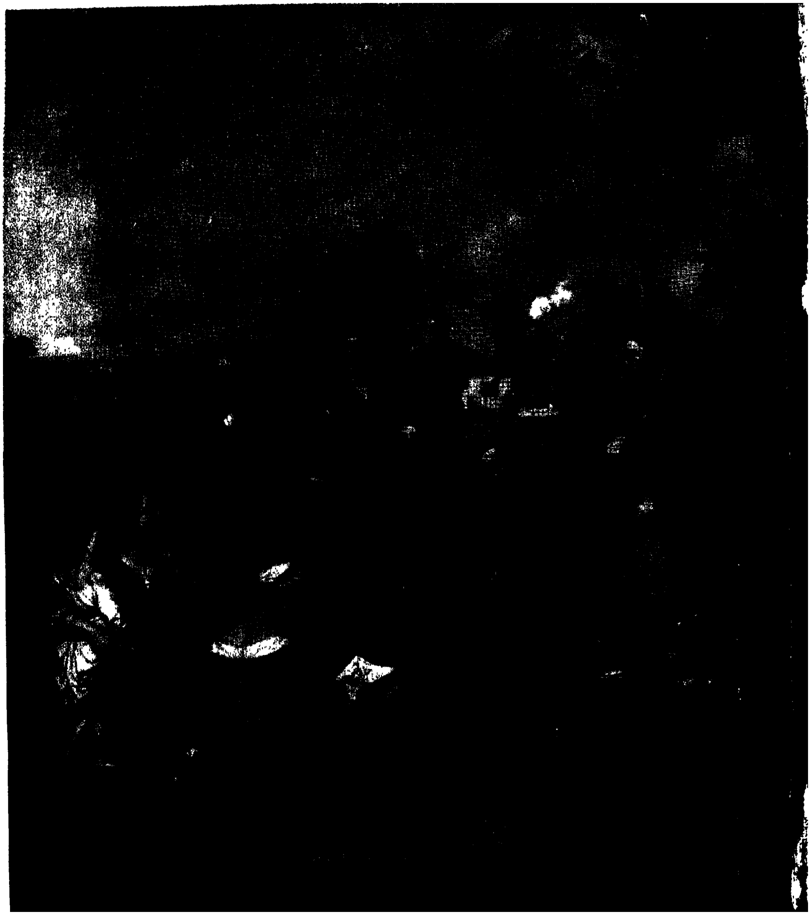


THE BIRTHPLACE OF THE LOCOMOTIVE

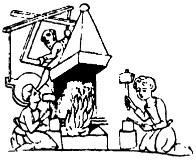
After a painting by John Lucas

In his *Memoir* of John Lucas, William Lucas gives the following description of the painting :

> " Mr. Robert Stephenson commissioned the painting of a quasi-historical picture which should focus, as it were, upon one canvas the achievements of his father, of whom he was so justly proud. The work . . . depicts the pitman's cottage, in which Robert was born, as it stood alongside the pit-rail of Killingworth Colliery in which George worked. And upon this rail George's first locomotive engine, nicknamed by his fellow workmen " Puffing Billy ", drawing coal from the pit mouth to its place of shipment. The group of villagers in the foreground discuss the merits of his " Geordie-lamp ", and in the distance is seen the North Eastern Line to Scotland."

John Lucas painted several portraits of the Stephensons, and it is considered that the three male " villagers " are likenesses of George Stephenson, his father and his son Robert.

PIONEERS
of British Industry



BY F. GEORGE KAY
F.R.S.A.
Author of "Royal Mail"

FOREWORD BY SIR NORMAN KIPPING
Director-General of the Federation of British Industries

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FOREWORD BY SIR NORMAN KIPPING

Director-General of the Federation of British Industries

THE remembered names in any age and nation are those of the pioneers, for enterprise more perhaps than any other quality is one that mankind calls “ greatness ”.

The circumstances of each age open [illegible] ent doors to enterprise. In the small world of the fir [illegible] zabethan age, geographical discovery and exploration ; i [illegible] period of the industrial revolution, industrial enterpris [illegible] nore recently perhaps, scientific enterprise, have stood [illegible] ove all other pioneer movements. In each of them the British were among the leaders. Each has brought in its train the growth of knowledge, the growth of wealth and the raising of the standard of life as measured by material things. Each in its early stages has brought with it some anxieties and even evils which have had to be mastered and overcome as pioneering gives way to organisation and development. Early geographical discovery led in some places to slavery, early industrial pioneering in some cases to sweated labour, and scientific discovery to new instruments of war.

These phases, now happily past in the first two of my examples, detract nothing from the achievement of these pioneers. It is they as much as any others that lifted the British people from obscurity into world leadership. Long may their spirit survive, for the world lives by progress, and the battle is to the strong and enterprising.

Our debt to individuals of genius is incalculable and our debt to those of the present and immediate future will be no less than to those of the past. Possessing in our island few material resources that can be exploited, we need more than any nation those men of genius, wit and skill who are ever striving to improve, to develop, to invent.

It is not easy to take a detached view of our own perplexing and critical times. But if we try, I think we shall find we have no lack of men of creative genius and with the necessary confidence and courage to persist. Mr. Kay has brought the story to our own time and, when the day comes for a new edition, I am sure the chronicle will not falter. However, we must not minimise the difficulties. Successful pioneering needs not only practical vision in the inventor but courage from his sponsors and substantial funds. It would be a sad business if pioneer discovery and development, which constitutes the very heart of enterprise, were stifled for lack of vision in their practical application by others or for lack of financial support because " risk capital " is taxed out of existence.

In the present century, Britain's contribution has been one to be proud of, as exampled by our work on atomic energy, television, radar, penicillin and jet aircraft. One thing we cannot afford is to be parsimonious and frugal with our present-day explorers.

It is a spur to endeavour to recall again the great names of the past. Mr. Kay has not only given us faithful sketches of notable individuals but has fitted them with skill into their social and industrial frame. His book is a contribution to a part of social history whose significance is only too liable to be neglected or ignored. Our problems of national husbandry to-day are more complex than in any past years, but it is certain that if we bring to them the originality, vigour and dogged persistence shown by the pioneer discoverers we shall emerge from this century—perhaps chastened and matured by experience—but triumphant. Rather than look nostalgically to the past let us take care to encourage the potential pioneers of to-day, for pioneers are always among us ; in that fact lies our hope and strength.

PREFACE

MOST of the events recorded in these pages are part of the Industrial Revolution in Great Britain. It is impossible to set down the precise dates of this crisis in human history. It had its birth in the invention of the water wheel, of type, of the loom. It continues with the harnessing of the power of the atom. But the phenomenal number of discoveries in the years between 1765 and 1830 marks a climax of achievement.

In recent times it has been the fashion to suggest that the Revolution was not a " good thing ". There were, of course, great evils in the servitude of men, women and children which accompanied the mastery of the machine, but they were not the fault of the inventors, who showed how wealth could be created with a lavishness never previously imagined. Mankind in general, and the British race in particular, gained inestimable rewards from the hopes, the sweat, and the misery which went into the creation of the modern world.

Some accounts of those efforts form the theme of this book. They are derived from the immense amount of literature on a subject which has done so much to keep alive the spirit of restless enquiry by showing the successes of the past. The author would like to express his thanks to the many writers of bygone days who recorded these events as they occurred, to the current activities of the scientific and trade associations, and above all to the Science Museum, all of which help to maintain the memory of those who pioneered in the fields of industry and technology.

Their aid with records and documents has been inestimable; and finally the author's gratitude is expressed to Mr. K. D. C. Vernon, whose invaluable comments and suggestions after reading the manuscript have done so much to help in the aim of a balanced and factual account.

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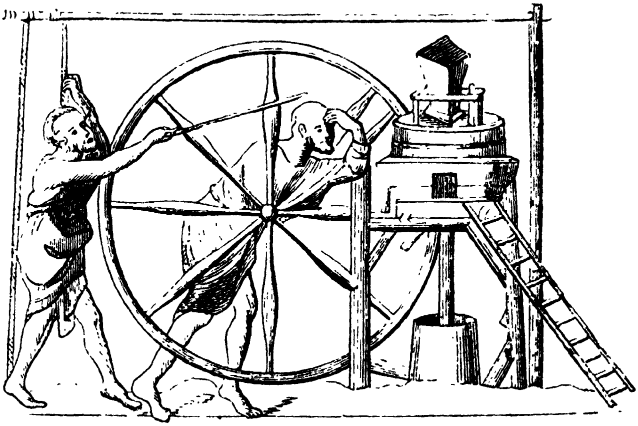

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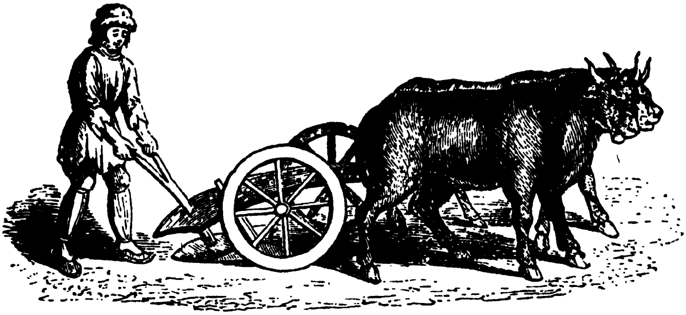
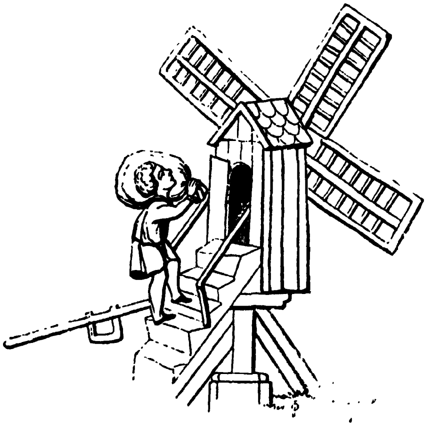


1 The plough, as shown in this drawing from a medieval MS., had changed little from pre-Norman times, and was still in use in the eighteenth century.



2 Windmills to grind corn were an early form of mechanical aid in agriculture in Britain.

1

FUEL FOR THE HUMAN MACHINE

PIONEERS OF MODERN AGRICULTURE

IN this century of near-miraculous machines which can impress by their monstrous size or by the intricacy of their delicate movements, the supplies of fuel to keep these devices in operation tend to be given the greatest prominence. Yet even in this age of mechanical supremacy the human machine is still the most important. In Britain to-day at least one-third of the energy consumed goes to maintain the human body's requirements of heat and nourishment. On a world scale the annual demand for energy is a gross intake of the equivalent of 4,000 million tons of coal. Of this, about 21 per cent. is supplied in the form of food from agriculture.[1]

If we regard a human being merely as a productive machine, then his engine is not particularly efficient. In the life of the average Briton of seventy years a couple of hundred tons of food will be required to maintain him in health and activity. Five-sixths of the nourishment he absorbs will be turned into heat for himself and are not available for energetic work. This food energy, measured in calories (a calorie is the amount of heat produced to raise 1 lb. of water through 4° Fahrenheit) is really the basic power of civilisation, and unless an adult man doing physical labour for eight hours a day got a regular intake of about 2,800 calories a day the whole machine of an industrial era would grind to a standstill. No ingenious use of atomic power, steam, fuel oil, or coal could prevent that happening in time.

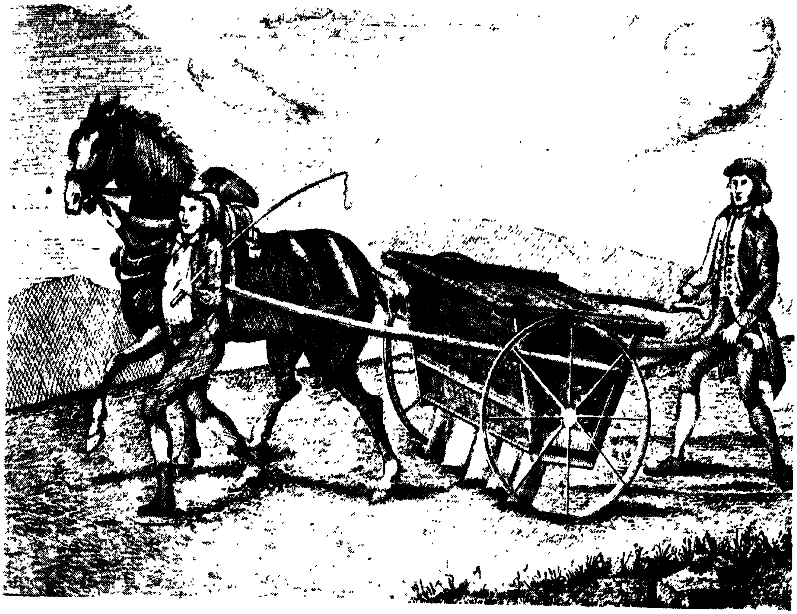
In order, therefore, to appreciate the way in which Britain grew into a great manufacturing power, we must not only look at the engineering workshops, the factories, and the business houses, but due regard must be paid to the fields of the smiling countryside of these islands, as fertile as any place on earth, and the huge areas where space has permitted farming on a mass scale. The importance of agriculture has for centuries been a subject of contention in Britain. The spectacular rewards which came from manufactured goods jeopardised the nation's primary industry of agriculture long before the conflict between landed and business interests of the nineteenth century. It began at least 300 years earlier, when wool production seemed such a simple way of gaining riches.

Many writers pointed out the dangers of such a policy. Thomas Mun, in *England's Treasure by Forraign Trade*, warned his readers that textiles were—

> the greatest wealth and best employment of the poor of this kingdom yet nevertheless we may peradventure employ ourselves with better safety, plenty, and profit, in using more tillage and fishing than to trust so wholly to making cloth ; for in times of war or by other occasions if some foreign Princes should prohibit the use of thereof in their dominions, it might suddenly cause much poverty and dangerous uproars, especially by our poor people, when they should be deprived of their ordinary maintenance.

The lesson has never been truly learned, though every time war comes, agriculture returns to its rightful place in our economy.

The first big clash between manufacturing and farming came in the fifteenth century with the agrarian revolution. It resulted in this country changing from a corn-growing land to a vast sheep farm. Farming for the production of food became subsidiary to the main job of tending sheep and processing wool on thousands of holdings, and where a dozen men and their families had once earned a living a shepherd and his dog were all that were needed. Slowly but inevitably the crisis came. The first signs of growth of industrial manufactures, the collection of the people who worked on them in urban communities, and the attraction this work made, not only to the farm labourers displaced altogether, but to



3 Scientific farming in 1787 : Wright's seed drill, developed from Tull's experiments which revolutionised food production.

those who earned a miserable agricultural wage, brought food shortages. The agricultural methods of the late fifteenth and early sixteenth centuries had been sufficient to produce food for a tiny population where those working wholly in agriculture outnumbered those otherwise engaged by two to one. Even then it had been " touch and go " in most winters, and for ordinary human beings the smiling face of England in April was a false one : it hid near-starvation.

In 1596 recipes for " bread " made of beans, peas, and beech-mast were published. At this time wheat cost 64*s*. a quarter, and towns like Norwich and London had to buy grain to relieve the distress of the poor. Even a century later an official report could only admit, as regards the children of the labouring classes, that all " they can have at home from their parents is seldom more than bread and water, and that was very scanty too ". Merrie England was not often very merry, and it certainly was in no position to found an industrial colossus served by millions of people.

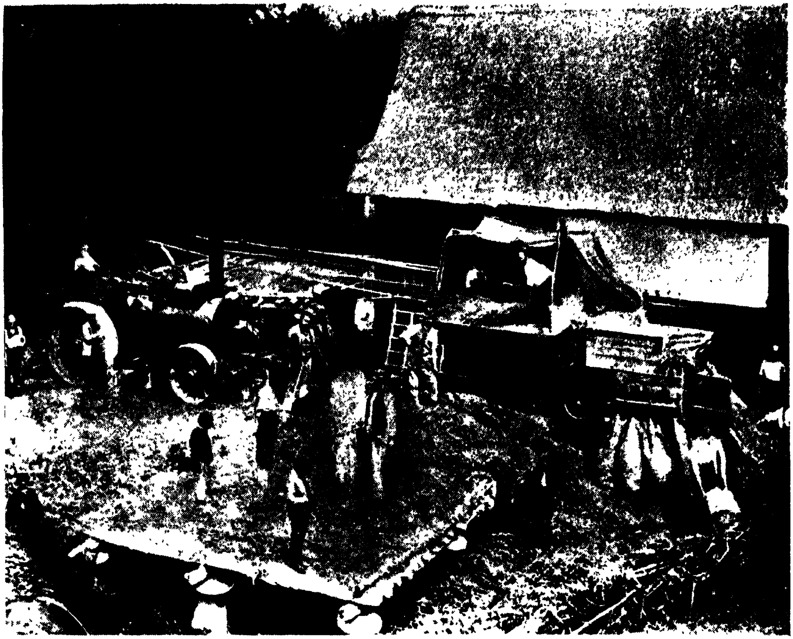
The crisis which was fast approaching was staved off by one man, who sat down and wrote, one day early in the eighteenth century :

> Some waste their whole lives in studying how to arm death with new engines of horror, and inventing an infinite variety of slaughter ; but think it beneath men of learning (who are only capable of doing it) to employ their learned labours in the invention of new (or even improving the old) instruments of increasing of bread.

The author's name was Jethro Tull. His attitude and his practising of what he preached were the very foundation of the industrial progress of Britain, a phenomenon of development and change which transcends anything before or since in its influence on the pattern of life of mankind. Tull invented something which enabled more food to be produced from the fertile but neglected land of the British Isles. This food enabled the population to expand, so that with the invention of machines powered by greater forces than the wind, water, and human muscles which had served humanity for tens of thousands of years, there were men to serve them.

Jethro Tull is little honoured to-day, and little known. Yet from his writings it is obvious that he could have been successful in almost any field of activity he cared to choose. Born at Basildon, Berkshire, in 1674, he matriculated at St. John's, Oxford, at the age of seventeen and then became a law student at Gray's Inn, being called to the Bar in 1699. His health was poor, and he had to leave London for the country. Strolling around the fields where he played as a boy, he saw that everything was being done much as it had been from the days of pre-history. He took up farming himself, travelling in Europe to note how Continental farmers worked (he was impressed with the tillage of vineyards), and in the next thirty years tried out many inventions while writing down his findings.

His main objection was to the picturesque method of sowing seed broadcast. His first drill was invented in 1701, and with it he reduced the amount of seed necessary to sow an acre



4 Steam- and man-power combined in a harvesting scene of Victorian England : threshing at Harlington, Middlesex, in 1868.

of clover from 10 lb. to 2. He also sowed wheat with his drill in foot-wide channels, using only a bushel to the acre and getting bumper crops because he could keep the weeds down in between.

As one might expect, Tull's neighbours resented the new-fangled methods of the lawyer turned farmer. They found no satisfaction when his method of sowing brought the best harvest ever known. Tull continued with his work of mechanising farming, and after inventing a drill turned to the problem of the plough. This simple mechanical device had changed little by the early eighteenth century from the plough illustrated in the Bayeux Tapestry of 700 years earlier. Tull produced a four-coultered plough which tore strong turf to pieces and made the earth more friable.

Next he returned to his drill. He started work on the design of a horse-drawn drill which was entirely automatic in making a furrow, sowing the seed, and covering it up. There is an enormously long book written by Tull which minutely describes his invention in words of lawyer-like precision. From it can be realised that this remarkable man was not really a practical technician but a visionary. He applied his mind to the problem and saw what was needed, and he took parts of existing mechanisms to produce the result he wanted. The 1733 drill, a very neat piece of work, was made up from a wheelbarrow as the cart; the seed box was based on the sound board of an organ (the parallel being the control of the passage of air and the passage of seed), and the cylinder was a cider mill. "This I hoped, for anything I saw to the contrary, might perform this work of Drilling", comments Tull, "and in this I was not deceived." A typically English piece of understatement.

As Tull's drill was hauled across the fields of England which had been turned over with his plough the first real development in agriculture since the late Stone Age took place. He showed the way to increase the yield of the neglected earth—and he also demonstrated what could be sown: the turnip. This homely vegetable, as Tull proved, could be grown in fields instead of the garden and provide cattle food for the winter. The decimation of the country's cattle every autumn simply because there was insufficient forage to keep them alive until the spring grass came was one of the main reasons why the English diet before the eighteenth century was inadequate. Perhaps, as a result of Tull's innovations, the roast beef of old England became a staple article of diet (there is, in fact, little evidence of this outside the song-writer's imagination), but prior to the nineteenth century meat was a luxury only occasionally tasted by the bulk of the population.

If we examine the great food festival of the year—Christmas—in earlier centuries, we shall obtain a good idea of the English diet, and incidentally appreciate how hopelessly inadequate were the supplies of such foods for a large industrial working population.

In earlier days, when history tends to report the customs and activities of the royal families and aristocracy as if they were typical of the nation as a whole, the Christmas dinner certainly did not affect the bulk of the population. Indeed, they were legally prevented from having the Technicolored feasts beloved of the film producers, at Christmas or any other time.

Food " fit for a lord " meant food which only he or those of superior rank could eat. This meant that on his table could appear whole animals, fish or fowl. No one else was permitted this privilege, and the custom was rigorously observed. In lesser homes even larks were cut into small pieces to signify acquiescence with the ruling. Nor was this the only rule which affected the so-called " good old-fashioned Christmas meal ". In 1470 a law about Christmas dinner stated that peers were allowed five dishes besides soup, gentlemen three, and meaner persons two.

One of the best accounts of a royal Christmas dinner is that of Henry V and his newly wedded Queen Katherine at Westminster Hall.

The first course was brawn and mustard, dedells in burneuax, frumenty, pike stuffed with herbs, lamprey, trout, codling, plaice, crabs, and tarts. The centre dish represented a pelican on her nest with her young and an image of St. Catherine.

For the second course the royal host invited his guests to try jelly covered with columbine flowers, white potage made from almonds, bream, conger eel, soles, barbel, roach, salmon, halibut, fried smelt, crayfish, baked lamprey, and flowers of camomile made from confections.

Those who could still manage it, tried a third course of dates, cream, carp, turbot, perch, sturgeon with whelks, roast porpoise, crayfish, prawns, roasted eels, and a leech " called a white leech " with hawthorn leaves and herbs.

This massive spread contains one meat dish—brawn. Fish is the basis of the rest, and the amount of this food which ordinary people could buy or catch may be conjectured. The truth is that in winter meat was a rarity, and protected by viciously hard poaching laws.

Tull's drill changed the situation entirely. The tall and heavy cornstalks which grew in fields cultivated with his machine provided straw which was turned into manure in the farm-yards. This in turn increased the fertility of the soil, and the turnips that grew the next season fed more cattle and more sheep; meat, butter, and milk became more plentiful. The turnip found a ready disciple in Viscount Townshend, whose experiments in farming at Raynham, Norfolk, which began in 1730, are historic. Nicknamed "Turnip Townshend" because the qualities of the vegetable were almost his only topic of conversation, Townshend developed the four-course system of cultivation which followed a wheat-oats (or barley)-greenstuffs-turnip four years' routine and kept land in constant cultivation without depleting it of nourishment. His work was ably carried on by Thomas Coke of Holkham, Norfolk, who inherited his estate in 1776, when the rent roll was valued at £2,200. By his brilliant agricultural work, the value had risen to £20,000 in 1816. Coke followed the practices pioneered by Townshend, but he was of far greater influence, because as a member of one of the leading families in England he was able to see that his precept was noticed and acted upon. Interested in every branch of farming, he encouraged those with ideas to come to his estate and discuss what they were doing. These conferences, known as Clippings, were both agricultural shows and scientific meetings. At first they were attended by tenant farmers and neighbouring owners. Later they attracted people from all over the world, as many as 7,000 guests attending the Clipping of 1821.

Coke's estate was a model for the world by the end of the Napoleonic Wars. He built his workers fine cottages, and his animals were better housed than many a town-dweller. The fertility of his fields came from heavy marling, with two straw crops and two of grass. His grassland was sown as carefully as his cornfields. Previously it had been the practice simply to sweep up the seed from the hay barns and sow that. Coke selected his grasses by experiment, paying the children of the district to search far and wide for the type he wanted. The trouble was well worth while, for he had luxuriant pastures in a place where, when he had inherited it, people said there was only one blade of grass and two rabbits were fighting over that!

He did not interest himself merely in crops. That change from a diet with very little meat of the earlier centuries to the Dickensian sides of beef and saddles of mutton which typified the middle-class English meal a century ago was largely due to Coke and his encouragement of other pioneers in selective breeding. Coke himself did much to improve the breed of beef and milk cattle with red Devons, and he also took up the breeding of Southdown sheep, the source of the best mutton there is to-day.

The earlier stages in this breeding of farm animals were in the hands of a number of farmers. Robert Bakewell, of Dishley, Leicestershire, tried inbreeding with the longhorn and achieved a strain which was an excellent dual-purpose one —a good milker and a better beef animal than had been known before. With sheep he had even more success. He evolved the new Leicester sheep, which was a producer of mutton rather than wool. As such it was a tremendous success. One of his breeding rams earned the phenomenal sum of 1,200 guineas in fees in the season of 1789.

Other men followed the examples of these pioneer stock-breeders. Bakewell's work with cattle was improved by two brothers named Colling, who farmed near Darlington. The shorthorn which is so well known to-day is largely the result of the Collings' experiments. Even the conservative-minded farmers who queried the desirability of their inbreeding methods soon had to admit their success, and the value of cattle, once rarely more than a pound or two, soared upwards as the new-fangled pedigree details became important. When Charles Colling sold up his farm on retirement, his most famous bull, Comet, bred in 1804, was sold for 1,000 guineas.

The work of these men gained greater recognition than that of men like Tull. That it did so was largely due to the demands of the new industrial population and the shortages caused by war, and also to better publicity methods. Coke's Clippings were, of course, one important system of disseminating scientific agricultural information and of knowing what one's neighbour was doing. Another was through the work of the Board of Agriculture, founded in 1793. Here the greater proportion of the early work was achieved by Arthur

Young, a man who had been an unsuccessful farmer, but found that his pen was mightier than the plough. With a tremendous flair for objective reporting, he portrayed rural England in the latter half of the eighteenth century, so that we have almost as graphic a picture of life in those times as if a cinema film had been made. Some of the surveys he made were for the Board. Other books were written because of his deep interest in an industry at which he had himself failed. If it is mentioned that his *Annals of Agriculture* runs to forty-five volumes, it will be seen that very few details of what was happening in the fields of the country were omitted as he rode around, observing and criticising.

Scotland led in the scientific investigation of growth, though the theories put forward unfortunately did little to persuade farmers to change from their rough-and-ready traditional methods. Prosperity would have been theirs if they had listened to the discoveries reported by Francis Home. Invited by the Edinburgh Society in 1755 to " try how far chymistry will go in settling the principles of agriculture ", Home showed that growth was stimulated by potassium nitrate, potassium sulphate, and sodium sulphate. Forty years later the Earl of Dundonald set down the outcome of his investigations into the value of phosphates and natural humus. The ideas of these two men were confirmed and extended by a series of lectures which Sir Humphry Davy delivered annually between 1802 and 1812 to help food production during wartime.

It was indeed fortunate that these men had helped to change the face of England when they did. The Enclosure Acts, which gathered land together from the age-old strips into larger fields, resulted directly from Tull's methods of cultivation. Although the legislation had most unfortunate repercussions in dispossessing smallholders and turning them into ill-paid labourers, there can be no doubt that the change came just in time. Without this more efficient food-production, Britain would have starved in the Napoleonic Wars, and the flames of revolution might well have spread from France to these islands, as indeed they almost did. After war broke out wheat rose steadily from around 50*s*. a quarter to 160*s*. A loaf, once 6*d.*, cost 1*s.* 5*d.* in 1801. A farm labourer might still be earning only £10 a year, with certain privileges, such as a free cottage and access to wood fuel, and the terrible position brought the ill-advised Speenhamland dole into operation, when the magistrates of a village near Newbury, in the county where Tull had started his farming experiments, agreed to raise a farm labourer's wages to 3*s.* a week for himself and 1*s.* 6*d.* for each dependent, when a loaf cost 1*s.* The result was to make the parish rates an almost impossible burden and to turn the farm workers into paupers totally dependent on relief.

The staple diet of an eighteenth-century working-class family was bread and cheese, with some butter and milk, except in the winter. Sir Frederick Eden, who wrote a treatise on *The State of the Poor* (published in 1797) gave the annual expenditure on food by a family of labourer, wife, and four children at Streatley, Berkshire, as £52 (their total income at the time was £46, so this family, like many others, was by the end of the century living beyond its income). The weekly amount of food was 8 half-peck loaves, 2 lb. cheese, 2 lb. butter, 2 lb. sugar, 2 oz. tea, ½ oz. oatmeal, ½ lb. boiled bacon, 2 pints milk. It is noteworthy that meat and potatoes are absent from this diet. Eden adds that the inmate at the Bedford Workhouse in the early part of the century was better off than the most industrious labourer, if he were employed in agriculture, who in turn was better fed than his contemporary in the factories.

The progress in agricultural methods and the consequent amelioration of working conditions, together with an increased output of food, was slowed down by landowners whose ambition was to reduce the rates by reducing the number of farm labourers. Thus Mr. Hodges, a Member of Parliament, in a speech well received in the House :

> I am quite satisfied that the erection of cottages has been a most serious evil throughout the country, and I have with others, pulled down between twenty-six and thirty cottages which, had they been left standing, would have been inhabited by young married couples,

He explained what was no doubt obvious to his colleagues : " They would have become nests of beggars' brats ".

Despite this sort of attitude, which was influencing farm labourers to emigrate, thus following the farm tools that were going for export instead of helping to increase the fertility of British soil, farmers and their workers achieved miracles during the Napoleonic Wars, when one in fourteen of the male population was in the armed services and imports were severely restricted. The farmers made fortunes at the same time, of course ; but the palmy days soon came to an end. Bad harvests, a growing population, and a growing sterility of the soil even with the improved system came to a climax in the Hungry Forties.

Solutions of the problem were available, and even being tried. Sir Humphry Davy called attention to the fertilising qualities of the bird dung from South America called " guana ", and the newly formed Board of Agriculture paid one William Smith the princely sum of £8 for a soil survey of the country. The formation of the English Agricultural Society in 1838 (later the Royal Agricultural Society) gave a great impetus to breeding.

Four years later an experiment began which has since revolutionised agriculture the world over. John Bennett Lawes in conjunction with J. H. Gilbert, began testing manures, both natural and artificial, at his home at Harpenden, Hertfordshire. Lawes discovered the method of making superphosphates by dissolving bones in sulphuric acid, a chemical method of speeding up the natural process of fertilisation by bones which farmers had used for centuries, their practice being to leave the bones in the fields for years until they had decayed. The Lawes' experiments inaugurated the famous Rothamsted Experimental Station, where ever since crops have been grown in areas for comparison, and any visitor may see the puny growth of wheat grown in a field which has had no manure ever since, a state which most of our farm land would inevitably have reached if the great trio of artificial fertilisers—superphosphates, sodium nitrates, and potassium —had not been discovered.

2

BLACK DIAMONDS

HISTORY OF BRITAIN'S COAL MINES

COAL is the very foundation of Britain's industrial wealth. If man has expended it prodigiously for century after century, Nature's lavishness has been equal to the extravagance. Coal will remain our paramount source of power for many a year to come. This importance has been recognised since an Elizabethan writer proclaimed coal as " one principall commoditie of this Realme ".

The story of coal-mining is at one and the same time a history of industrial progress and a record of horror. In the former sphere the need for coal inspired the invention of the steam engine and the railway, and the development of manufactures sprang from lavish and cheap supplies of fuel ; in the latter is the unpleasant truth that mining remained —and to a great extent remains—an industry where men's muscles and lives are the essential materials needed to bring this priceless fuel from the interior of the earth to the surface. It is an attitude from which most of the labour and economic troubles of the past thirty years have arisen. The fact that miners have been regarded as a " race apart " from early times is hardly an excuse for the continuation of such ill-founded traditions. Yet they persist. Early reports of the use of coal cannot be substantiated, because the word " fuel " normally referred to wood, and even where coal is mentioned it usually means charcoal. There are, however, indications that coal burning in Britain took place in far distant times, and not accidentally. A burial jar found in a Bronze Age barrow in the Vale of Glamorgan contained pieces of both burned and unburned coal among the charred bones and wood ash. Ash deposits in the Roman camps along Hadrian's Wall also contain coal.

In the Anglo-Saxon period coal was used to make buttons, spoons, and similar small articles, in much the same way as jet, and in the Dorset area Anglo-Saxon money tokens or brooches of coal have been found. For this sort of work the cannel coal of Wigan and the peacock coal of Staffordshire and elsewhere were most easily cut and fashioned. Sometimes coal was used for constructional work, the aisles of churches being paved with coal slabs, and as late as the seventeenth century there was a summer house on an estate at Haigh, near Wigan, with roof and walls of coal.

The mediæval monasteries in the North of England and Scotland undoubtedly used coal for their forges and possibly for cooking and heating. The many establishments of religious orders in Northumberland had easily-obtained sources of coal in outcrops, and some of them used to pay for coal brought by women and children who gathered seaweed along the Northumberland coastline. None of the early Norman records indicates that much money was ever spent on sinking shafts or even excavating very far by the monasteries, and it was not until Magna Carta and the ancillary legislation gave landowners the right to dig pits on their own property that the bell type of pit was common. In this the miner dug off the top-soil and then worked outwards into the coal seam until the upper ground caved in. Then he started another pit of the same kind a few yards away, following the seam until it went too deep.

Coal was very soon being excavated in considerable quantities along the Tyne, and some of it came by sea to London. The wharf was just below the present Blackfriars Bridge, and by 1228 the road leading up from the Thames to Ludgate was called Seacole Lane. The coal was not used for domestic purposes, but by lime-burners, brickmakers, and ironmongers.

A fillip was given to the trade in 1239 when Henry III granted to the citizens of Newcastle the right to dig coals and stones in the common soil outside the walls of the town and convert them to their own profit. Thus began the enormous coal trade of Newcastle, to the profit of the townspeople by trade and levies on the coal loaded on the Tyne,

5 The prehistoric swamp forests which became Britain's foundation of coal.

and to the King and Government in London, who found various revenue-raising devices of export tolls. These taxes did not strangle the flourishing industry—one which, by the seventeenth century, gained the title of the Black Indies for Durham and Northumberland.

The difficulties of transport precluded the wide exploitation of the inland coalfields even where their existence was known, but in Scotland the proximity of coal to the Firth of Forth and the Clyde stimulated mining to an extent comparable with that of Tyneside. In the middle of the sixteenth century some 40,000 tons a year were being dug from the Scottish pits, and this figure rapidly rose. James VI of Scotland did much to extend the use of coal in London after he ascended the throne of England as James I. James was a friend of one of the most enterprising coal-mine-owners of the seventeenth century—Sir George Bruce, who owned a mine at Culross, Fifeshire, which had been worked by monks for centuries before he took it over in 1575. The Culross mine was of a unique size for that period and a long time after, for the galleries were miles in length and one ran out under the Firth of Forth for about 1,000 yards and then by a shaft to an isolated wharf where two horses worked a windlass to draw coals direct from the workings and load them on to the boats moored alongside. The worthy but somewhat neurotic King returned to Scotland to visit friends in 1617 and was conducted on a tour of the mine's galleries. He found no cause for alarm when underground, but on ascending to the man-made island in the middle of the Firth he imagined that this was an ingenious trick to capture him, and exclaimed " Treason ! "

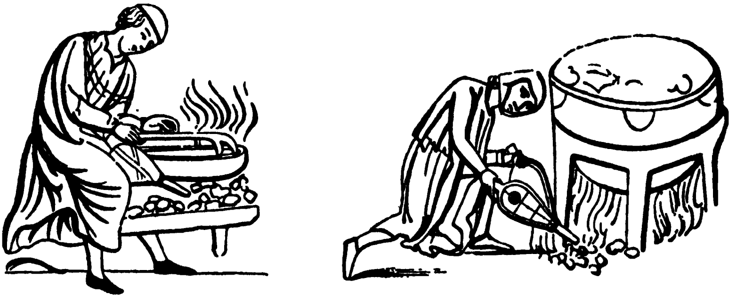
Imagination fails in estimating the work which must have gone into the construction of the Culross pit, for it must have been grubbed out with only the simplest of tools. The miners who did it were less free than other workers of their day.

In the ancient world mine work was carried out by slaves or criminals. Neither class could count on the slightest touch of humanity in their treatment. Even tools were sometimes not supplied, and there were ore mines in Europe worked by the Romans with slave labour where to this day the scratchings of thousands of fingers as the miners worked with their bare hands can be seen imprinted in the clay walls of the passages. Although there were many mines in the Forest of Dean which were worked by groups of miners for their own benefit, those in Scotland and the North of England imposed conditions of serfdom. The mines were in the hands of the great landowners, and both the coal deposits under their estates and the men who worked them were regarded as part of their property. In the sixteenth century, when miners were digging the Culross mine, for example, the Scottish Parliament passed an Act whereby miners who set coal-mines on fire were guilty of treason. On the death of the landlord mines and miners were transferred to legatees or sold as a complete working enterprise. The expansion of the coal-mines made it possible for a skilled miner to get another job easily, except that a law was passed in 1606 which forbade an employer to engage a miner who did not hold a testimonial from his previous master. This was virtually impossible to obtain, and so the Scottish coal-miner was bound for life. Not until 1799 was this mine serfdom abolished.

Conditions were almost as bad in the Northumberland coal-fields. In 1765 there was a strike of miners in the Tyne and Wear areas. The custom in the north-east was for the mine masters to hire miners on a Yearly Bond, paying a hiring fee of 1*s*. The expansion of the coal trade resulted in a shortage of labour and the 1*s*. was often increased to as much as 3 guineas. In 1765, at the annual re-engagement, the mine-owners refused to employ a strange pitman who had no leaving certificate—which meant, in practice, that no one could change his job.

The miners held out for six weeks against conditions which they suspected bound them to one master for life, and in the comments made at the time some interesting details of working conditions were revealed. Miners were unique at that period in their hours of work. In winter-time all surface activities in agriculture, weaving, and so on were largely controlled by the hours of daylight, and in winter-time, at least, ten hours were the maximum. But the miner, who always worked by artificial light, toiled for sixteen or seventeen hours a day throughout the year, for which he earned 1*s.* 2*d.* and was compelled to spend it at the " tommy shop " run by the mine. There were 4,000 miners involved in this dispute, and the cessation of work until October made coal both dear and scarce in London that winter—an early symptom of the way economic life of the country could be upset once the mainspring of the machine, the miner, laid down his pick. The Yearly Bond trouble caused a further dispute in 1810, and it was not entirely eradicated until 1872.

By 1841 about 120,000 persons were employed in the mines (the figure included 2,350 women). This does not give a true picture, because many women and still more children were in the mines unofficially, going there to help the head



6 Where coal outcrops occurred medieval artificers in metal made use of the fuel instead of wood.

of the family. Nothing can ever excuse the bestial attitude of the owners and overseers in ordering or condoning the employment of wives and children in the mines, but it is only reasonable to point out that the miner himself saw little wrong in the practice. No one imagined that a labouring man could support a wife and family on his wages, and in no industry at the time did he do so. Children were made to contribute as soon as they were able to walk and understand orders. A woman worked because she knew it was the only way to avoid starvation for her man, her children, and herself.

The smallest children worked the ventilation traps, squatting naked in a niche in the coal face for twelve hours a day, always in complete darkness and often in a few inches of water. At six or seven they hauled the loosened coal to the main shaft, where their mothers and elder sisters heaved it along on sleds attached to a leather band on their foreheads, the ropes passing between their legs as they crept about on all fours.

The legislation of 1833 referring to conditions of employment in mills did not affect mines, and it was not until 1843, through the work of Lord Ashley (later Lord Shaftesbury) that an Act was passed forbidding the employment of women and boys under ten in mines. But women still went down, disguised as men, and boys eight years old, " small for their age ", were in the pits for years afterwards. As late as 1851 women were still hauling tubs underground in the South Wales coal-fields.

The importance of the labour situation in coal-mining was due to the phenomenal growth of the industry. During the sixteenth and seventeenth centuries it expanded on a scale quite commensurate with that of the Industrial Revolution. The Durham and Northumberland coal-fields were yielding something like 65,000 tons a year when Elizabeth came to the throne, and by the reign of Charles II this figure had reached nearly 1½ millions, despite the stagnation which had occurred during the Civil War. The scene on the Tyne during the summer months must have been busier than on any other river in Europe. As many as 500 ships would be loading from the hundreds of keels (river boats) which brought the coal down from the mines along the banks of the river. Some of these

A wagon-way in the Newcastle coalfields as it appeared in 1773. Mining had been a industry of Tyneside for five centuries before that.

8 George Stephenson's locomotives and railway at the Hetton colliery, *c.* 1825.

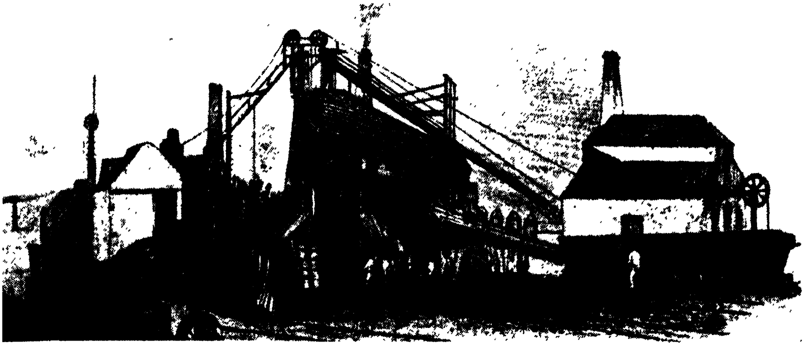
vessels were foreign, for *charbon de roche* was being imported as early as 1200 by the French and still more went to the Low Countries, used as ballast after corn had been delivered.

Not all of the coal was sent away. Huge quantities were used for making salt. In 1591 Robert Bowes of Berwick built salt pans at Sunderland, building the fires with coal dug from mines which he opened at Offerton. Salt works sprang up everywhere—notably at Whitley and in the Firth of Forth. The development of the Scottish salt-making industry was largely due to Eustachius Roche, a Fleming, who came to Scotland about 1590.

The Clyde Valley pits were on a smaller scale, but by 1620 there was a steady trade in coal with Ireland, the ships loading at Dumbarton. Ireland also took coal from South Wales, though here also development came comparatively late. In the eighteenth century, however, Milford was a large and flourishing coal port, and mines in Pembrokeshire and Glamorganshire were well established.

The names which appear in the early history of mining are mostly of the landowners who were fortunate enough to find deposits on their estates, and they cannot be said to have contributed very much to the advancement of technique. Some had coal-mines thrust upon them by the fortune of birth; a few deliberately sought out the fields and exploited them. One of the most colourful characters among the second class was Huntingdon Beaumont (a cousin of the Tudor playwright), who rampaged about England buying up rights and influencing finance for mine-sinking. Mineral leases in Warwickshire, Staffordshire, and the Trent Valley were obtained by him, and though he finished his life a poor man he contributed much to early seventeenth-century development. He invented —or first used—boring rods for prospecting by which a hollow rod was twisted into the earth to obtain samples and so replaced the usual expensive and slow method of digging a trial shaft.

Beaumont's work was necessary and timely because the shallow workings were rapidly being exhausted. Mines were going deeper—and the problems of gas and water became acute. Minor flooding had been tackled since 1500, when



9 One of the country's earliest collieries : St. Hilda's, Wallsend.

water was drawn out mechanically, and in the Durham fields a chain of buckets was being used. By 1600 the Trent Valley pits were using an ingenious rag-and-chain pump. In this system a long, hollow cylinder of wood was placed vertically in the mine shaft and a chain, on which lumps of tough cloth were tied, passed through the cylinder. Turned by a horse, a few blind men, or boys, this brought up a considerable volume of water as long as the rags fitted tightly in the cylinder. One pit where this system was used was at Wollaston.

The deeper the mines went the greater was the volume of water collecting in the workings and the greater the difficulty of raising it. At Ravensworth on the Tyne during Charles II's reign three wheels raised water in three stages for a total of forty fathoms. This disposed of more water than the other method common on Tyneside of the bailing gin, where one bucket was lowered while the other was drawn up on a simple drum and rope mechanism.

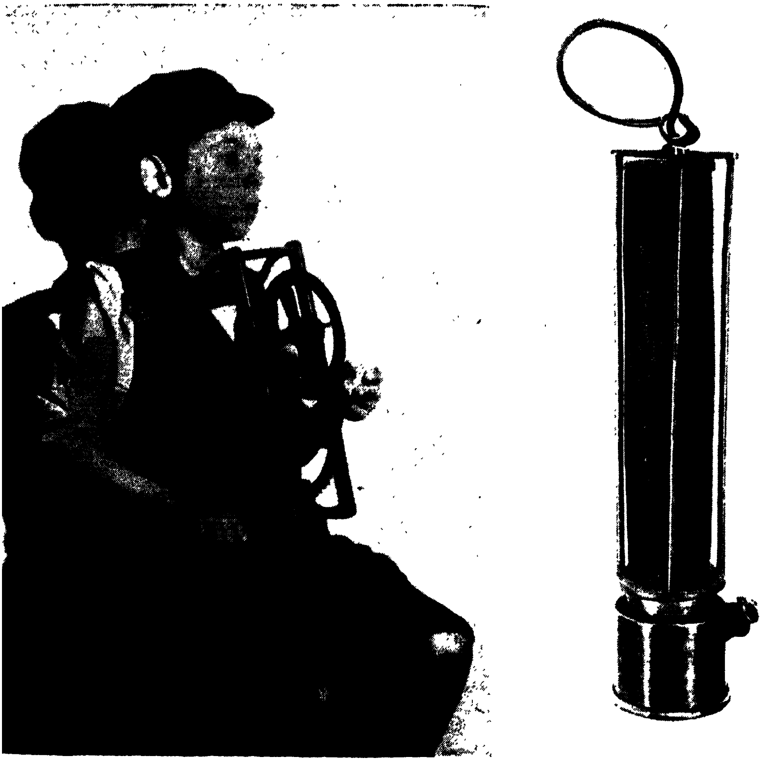
In the seventeenth century the first patents on mine-pumping machinery began to appear. Robert Crump obtained one in 1618 for a suction pump, and in 1631 David Ramsay, a clock-maker, patented a device to " raise water from coal pits by fire ". The Royal Society, which received its charter in 1660, devoted much of its work during the early years of activity to the flooded mine problem, and, as is described in Chapter 3, the steam engine was invented for pumping purposes. The first engine was erected in a Staffordshire mine in 1712. Six years later they were at work in Northumberland and Durham, and by 1725 along the banks of the Forth.

Water made work impossible; gas made it dangerous. Suffocation by choke damp or death from fire damp explosions were regarded as inevitable risks, and until well into the nineteenth century no inquest was held on miners who were killed at work. The earliest methods of insuring ventilation was to build two shafts at opposite ends of the mine. To create a movement of air a fire was lit in a brazier at the bottom of one shaft. This inevitably caused explosions which blew back into the workings. In many pits one miner, called the Penitent because of his cloak and hood, used to crawl on his belly pushing a lighted candle in front of him, and fired the gas, a foolhardy system which, needless to say, often had fatal results.

One of the first scientific approaches to the problem of ventilation was made by James and Carlyle Spedding in a deep mine at Whitehaven. These two engineers were father and son, and most of the system called "coursing the air" was developed by the younger man, James. He built brick walls, airtight doors, and wooden conduits to ensure that the air reached every part of the workings. It was only in large mines that this method failed when the single current of air became too heavily charged with gas, and so a system of splitting the working into sections was started.

Despite the improved ventilation, the use of gunpowder to blast the coal and of naked lights sent the death roll through explosions steadily upward. Carlyle Spedding invented a steel mill (*see* Chapter 21) after a serious disaster in 1740 at Whitehaven. A boy was needed to turn the wheel and the machine was expensive. It had one useful feature; when gas was present the sparks turned blue and the miners received a fair warning. Sometimes the sparks ignited a sudden escape of gas before the colour change was seen, and the steel mill was regarded as little better than the naked light.

Dr. Clanny invented the first safety lamp in 1813. Air was pumped to the flame through water by the inevitable miner's boy required by all the devices of the period. In 1815 George



Two early methods of safety lighting in the pits: Spedding's steel mill and Davy's lamp.

Stephenson produced his " Geordie " lamp, as it was called by the Newcastle miners, and in the same year Davy produced various safety lamps (see p. 251). It is noteworthy that all three men had no desire to derive any profit from their lamps : none of them patented their designs. Another safety device was Roberts' gas mask, perfected in 1825.

Despite the use of safety lamps and the use of steam engines to improve ventilation, explosions still occurred at the rate of three or four a month. Some were due to miners' carelessness, some to the inefficient installations of greedy owners. Public indignation resulted in the first Act for safety in mines in 1850. But neither miners nor owners realised that coal dust itself could explode. Not until 1923 did Sir William Garforth show that mixing stone dust with coal dust prevented the increase of heat to danger point. This study still continues in laboratories at Sheffield and London and in explosion galleries at Buxton, for the danger of the mines, as radio and press bulletins all too often show, is still unconquered.

Indeed, the great inventors of the coal industry may be of the future. Machine-cutters are a very recent innovation and are open to improvement. The gasification of coal in the mine is not yet a feasible proposition if all the heat and gases are to be used as they can be with mined coal. The turning of coal into oil is justified when normal sources of oil are unavailable, as in wartime, but with the production of 1 ton of oil from 4 to 5 tons of coal much improvement awaits the work of some future inventor.

Few names have been mentioned in this chapter—fewer than in any other so far as revolutionary ideas and innovations are concerned. The colossal contribution of coal to Britain's industrial fame has been in the hands, not of a few geniuses, but of the tens of thousands of sweat-stained, grimy men, women, and children who over the centuries have lived their lives grubbing and hacking into the treasure chest so securely hidden below the surface of these islands. For the miners of Britain there is surely a place among the famous of our industrial era.

Like the other ancient worker so typical of Britain, the labourer in the fields, the miner provided the bricks with which the great industrial strength of the nation could be built. Abundant food and abundant coal have always solved this nation's main problems. Given those two, our trade has never had to fear competition.

Coal in particular was the direct stimulus to inventive genius at the birth of the Industrial Revolution. It could provide great heat very quickly and in a confined space. Used to raise water to boiling point, it released energy. Fire, the ancient servant of man, was now to be allied in a practical manner to another element—water. Thus, as we shall see in the following chapter, a formidable new source of virtually unlimited power was harnessed.

3

THE IMPELLENT FORCE OF FIRE

INVENTION OF THE STEAM ENGINE

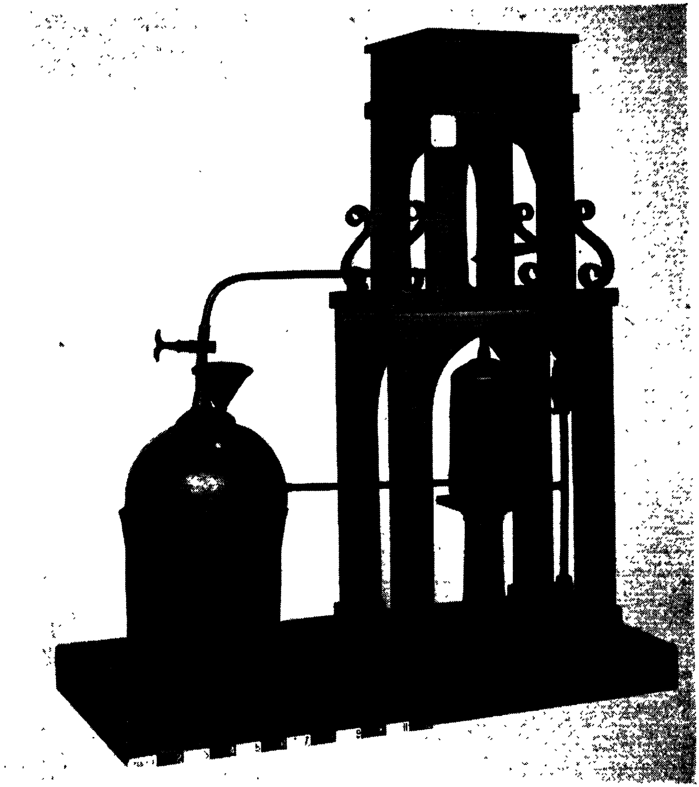
FROM the time of Hero of Alexandria, and doubtless before, men of imagination and vision were wondering how the energy released by heat could be controlled and used. The most spectacular effect of fire, seen almost every day in the cooking pots, was the power which heat created from water, and we would discredit the intelligence of man if it were considered that no one ever noticed how the lid of the boiling pot was forced upwards until the youthful James Watt allegedly did so. Many known and probably still more unknown people tried to do something with this power long before Watt. That they failed to do so was due principally to the lack of materials which would enable the necessary pressure to be raised or the pivots and pistons to be constructed. Timber, which was used for such simple machinery as existed in water- and wind-mills, might have served for movable parts, but the boiler would have most certainly been beyond the powers of ancient craftsmen.

Edward Somerset, Marquis of Worcester, is generally regarded as the earliest English inventor of steam engines. The noble gentleman was the author of a book entitled *Century of Inventions*, published in 1655. He was incarcerated in the Tower of London for a time, and it was in this period that most of his book was written. As one might expect from a work of reminiscences, beliefs, and prophecies produced in solitude, it is somewhat difficult to sift the wheat from the tares, particularly as Worcester followed the popular will-o'-the-wisp of perpetual motion and seems to have considered that a steam engine might produce it. His engine was really a vacuum pump on which he conducted experiments in Vauxhall after the Restoration. In 1663 an Act of Parliament gave him monopolistic rights in a " water commanding engine " which, if the machine had worked and the legislation had been upheld, would have made his descendants very rich indeed.

The first commercially successful steam engine was the design of Thomas Savery, who was born at Shilstone, Devonshire, about 1650. His famous patent of 1698 was for an engine which was intended " for raising of water and occasioning motion to all sorts of mill works by the impellent force of fire ". The engine worked by condensing steam in a vessel which sucked water into a partial vacuum and then, with the aid of another vessel, steam pressure drove the water higher. At first someone had to switch the steam from one vessel to the other, but in later models this was automatic. The Savery engine, wasteful of fuel as it was, marked an important step forward. For the first time it was possible to raise water to heights greater than 34 feet (the highest it will go when sucked into a vacuum) and some of his engines raised water as much as 300 feet, though Savery is fortunate to have escaped injury from the explosion of a boiler producing such a head of steam : he used no safety valve.

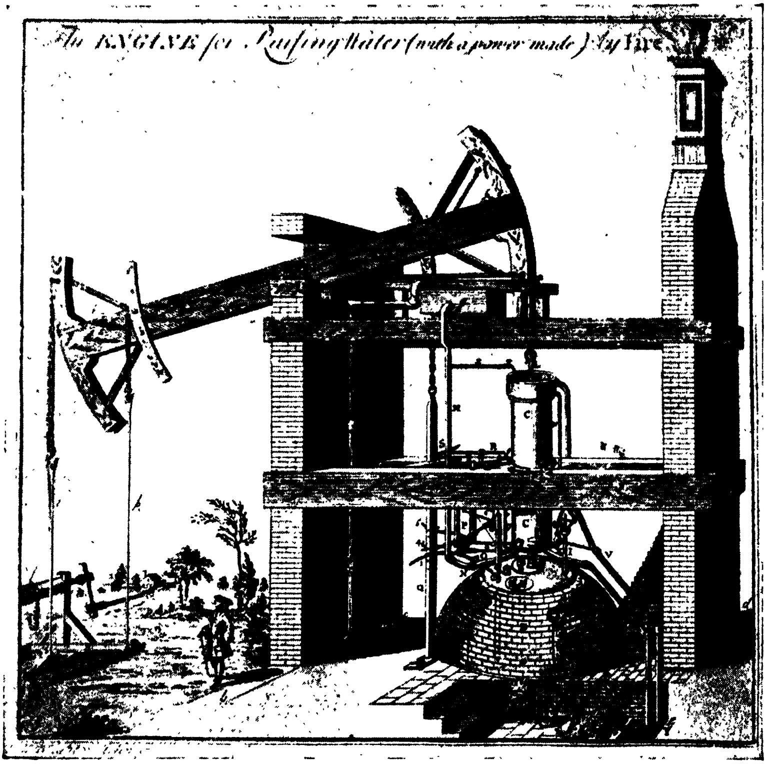
The lack of suitable material was Savery's chief obstacle against permanent success, for he had to use hammered copper soft soldered together for his boiler and receiver ; the taps were of brass, and the pipes of wood. Leakages wasted much of the power, and the boiler seams soon gave way. However, for raising water 50 feet or so the Savery engines were quite suitable, and they performed good work in mines and in providing domestic water supplies for large houses. Savery's invention is still used all over the world, an improved version having been devised by C. H. Hall in 1872.

About the same time as Savery's invention of his pump a French refugee living in England, Denis Papin, was working along a line of his own. His engine necessitated too much manual work to be of any practical use, though it was notable in that it employed a piston. In order to work the piston by suction, the operator had to pour some water in the cylinder, push a fire underneath, plug the water hole when steam



11 A model of Savery's steam engine, constructed about 1740.

appeared, and remove the fire so that the cooling steam formed the necessary vacuum to draw the piston up. Papin's subsidiary invention which arose from this engine was vastly more important: the safety valve. This was part of a device of Papin's which has only recently come into widespread use—the pressure cooker. About the year 1680 he prepared a supper of meat and poultry for the members of the Royal Society, showing that by cooking the food in his enclosed pot the pressure of steam completed the process in a few minutes and also reduced the bones to the consistency of jelly. The



12 The Newcomen pumping engine: an explanatory drawing produced in 1717.

cautious Papin, who may have had some unfortunate experiences in his preliminary experiments on these culinary arts, included a valve held in position by a weight. There is no basic difference in the design of the safety valve on every steam engine in use to-day.

In the year that the Marquis of Worcester secured his Parliamentary Act, Thomas Newcomen was born at Dartmouth. He became an ironmonger, and he was helped in his early experiments by a Dartmouth glazier named John Cawley or Calley. His aim was to build steam engines for pumping water out of the mines in the West Country, and these were exploited under the Savery patent, which covered all devices using steam to produce a vacuum. All three men were identified by a new monopoly granted in 1705, by which time the first Newcomen engine had presumably been built, though the first reliable evidence of one in use is in 1712. The Newcomen engine was a large machine. A large beam, pivoted in the centre, was heavily weighted at one end and connected to a piston at the other. The first operation was to admit steam into the cylinder. The piston then moved to the top, not through steam pressure, but by the pull of the counterweight. The steam was shut off, and a tap turned on to play cold water into the cylinder. This condensed the steam, created a vacuum and pulled the piston down again. Both steam and cold water had to be controlled by hand in the early models. With practice it was done quickly, and a dozen strokes a minute were achieved. Boys were employed for this job, and there is a story that a lad named Humphrey Potter, somewhat reasonably bored by the repetition of tap and valve turning every five or six seconds, made the machine do the job by tying various bits of string to the moving beam until he made the whole business automatic. A youth of this name may well have lost his job through the device, but it was much more likely to have resulted from careful thought by Newcomen, who would have seen that his engine's greatest defect was this on-and-off business.

The Newcomen engines became justifiably popular, and before he died in London in 1729 Newcomen knew they were being used to pump water out of coal-mines and to fill the reservoirs of water-mills in all parts of the country. By the time that a sickly baby named James Watt struggled through the first weeks of life in a Greenock cottage in 1736 the Newcomen engine was firmly established.

Watt was a born mathematician, working out geometrical problems on the stone floor of his home when other boys were playing truant from school, and he found no difficulty in earning a comfortable income as a maker of mathematical instruments and similar scientific apparatus, principally for Glasgow University, after he removed his business from London. One of the lecturers at the University asked him to repair a model of the Newcomen engine used in the physics department. Watt was then twenty-eight years old. On examining the model, he quickly realised that the great defect in the Newcomen engine was that the alternate heating and cooling of the cylinder wasted energy. He spent the next two years in analysing the faults and trying out corrections for them. He surrounded his cylinder with a jacket to retain the heat, and he condensed the steam in a separate unit so as to provide the necessary vacuum. Next, in order to maintain the heat of the cylinder, he invented the stuffing box kept pressed against the piston, and so the steam, though of low pressure, pushed the piston as well as causing the vacuum which pulled it. Still further improvements in fuel economy were effected with his discovery of the way to use the expansive power of steam. Previously steam was admitted at boiler pressure during the entire movement of the piston stroke, so that it was exhausted while at full pressure. Watt admitted steam only at the commencement of the stroke—a mere fraction of the amount used to fill the whole cylinder. The Newcomen engine provided 4⅓ million foot-pounds of energy from 1 cwt. of coal. When Watt's ideas were put into his engine the same weight of coal provided 39 millions.

Double-acting cylinders in which the steam was introduced alternately on each side of the piston, and the governor which is still the basis of all smooth running of machinery were other inventions from Watt's fertile brain, and it must be remembered that they were all applied to low-pressure steam engines, for although Watt recognised the potentialities of high pressure, he knew the limitations of metallurgy and confined himself to pressures below 7 lb. per square inch.

All these wonderful devices for turning heat into energy naturally took a long time to perfect, though most were considered as a direct result of his examination of the Newcomen model. The story of Watt's work now moves to the mansion of Kinneil, once the country seat of the Dukes of Hamilton, and at the time of Watt's stay there the family home of Dr. Roebuck, owner of the ironworks at Carron.

Roebuck had sunk coal-mines on the vast estate and soon

13 A Boulton and Watt pumping engine built for the Birmingham Canal Navigation in 1777.

struck water. The Newcomen engines which he brought to pump it out did not work as well as he had hoped, and on the advice of a friend of his, Professor Black of Edinburgh, he got in touch with James Watt. Roebuck persuaded Watt to give up his instrument-making and to start to build a full-size working engine in one of the outbuildings of Kinneil House. To influence Watt, Roebuck promised skilled English workmen to help him and added that he would cast the cylinders himself.

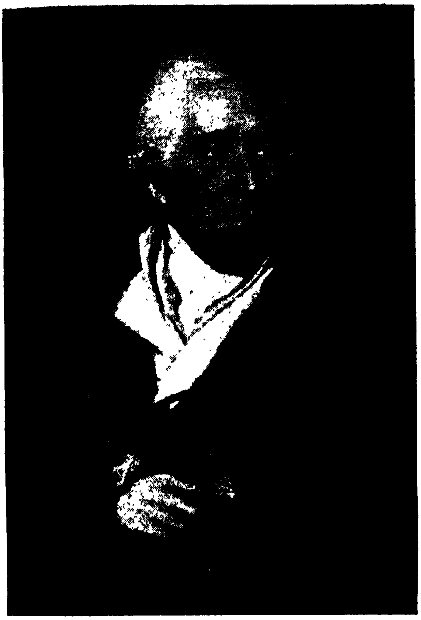
Watt arrived at Kinneil in May, 1768. It was a bright interlude in a story of disappointment and money worries. Watt was heavily in debt and his health was bad. When Roebuck sent for him he was on the point of abandoning his invention in despair, not that there was anything particularly wrong with it beyond the lack of the right materials, but because Watt was always ready to look on the blacker side.

14 A room which gave undreamed-of power to mankind : James Watt's workshop.

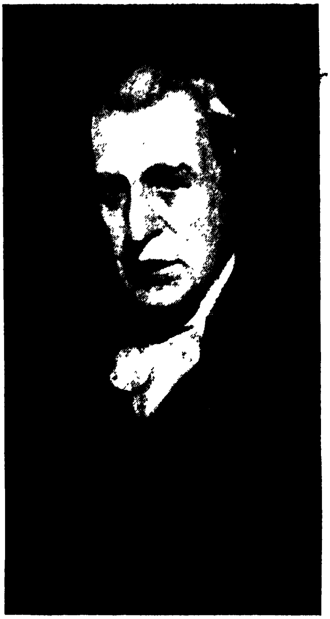
As a lifelong sufferer from migraine, he may be forgiven for occasionally wondering if years of search for success were worth while. Roebuck was just the inspiration Watt needed. He was an ambitious industrialist, a clever scientist, and a lavish spender if he thought an investment worth a risk.

Roebuck took a two-thirds interest in the rights of the invention, paid Watt's £1,200 debt to Professor Black, and promised to pay all the legal fees on patents. By the beginning of 1869 the patent was in force, though Watt's engine was unsatisfactory. Success was still some way off.

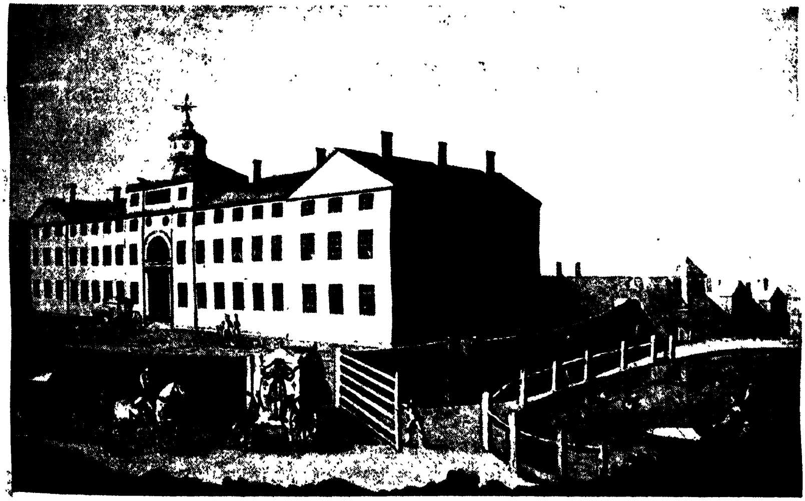
Roebuck's main idea in getting in touch with Watt was to use his engine instead of the Newcomen models to pump water from the new coal-mines. The engine remained unfinished, and the mines continued to get flooded. Roebuck expended first his own fortune, next his wife's, and finally money borrowed from friends and relations to try to get the coal. Still Watt's engine was not ready and Roebuck was compelled to sell his interest in it, along with everything else,



15 Matthew Boulton.



16 James Watt.



17 The famous Soho works of the Boulton and Watt partnership.

to appease his creditors. The rights in the engine were not itemised by the creditors, because they did not regard them as worth one farthing. They passed to Matthew Boulton of Soho, Birmingham, a maker of buckles and similar small items of metal.

All Watt could do when this catastrophe occurred was to wish his engine was ready. "He has been a most sincere and generous friend", he said at the time; "and is a truly worthy man. My heart bleeds for him, but I can do nothing to help him; I have stuck by him till I have much hurt myself; I can do so no longer; my family calls for my care to provide for them."

Had Roebuck but known it, both his protégé and his mines were within an ace of achieving a fortune for him. The famous Blackband ironstone was hidden a few feet above the roof of one of the coal seams, and Watt's engine was the nucleus of a great industry long before Roebuck died in comparative obscurity in 1794.

Matthew Boulton was able to put the finest engineering works and the most skilled engineers at Watt's disposal. Success was now assured. The first engines were pumps, but in 1781 Watt patented a device for turning the movement of the piston into rotary motion. The date stands out in the history of the Industrial Revolution, for it meant that factories no longer needed to find suitable rivers to provide power. They could go whither their raw materials were most easily transported or, better still, where the coal to drive the engines was most cheaply obtained. The era of the industrial city had arrived.

Watt's first idea was a crank between piston arm and wheel. It was so simple that he did not consider it patentable. Unfortunately, one of his workmen talked too much and an engineer named Matthew Washborough of Bristol rushed through a patent on the crank and flywheel principle. Just to show his inventive resource, Watt devised five different methods of providing rotary motion from his engine and patented them. The system he used on his engines was called sun-and-planet gear, in which a small geared wheel (the planet) revolved round another geared wheel (the sun), itself on the same axle as the larger driving wheel.

The Scottish instrument maker who had found it difficult to find financial support in his early years discovered that success brought a very different situation. Almost every idea he had was stolen and patented, whether it worked perfectly or not. When Watt completed his own work on it he found it impossible to use because of these dishonest moves. For nearly ten years he was involved in almost constant litigation—a period which made him an excellent lawyer, but deprived the world of his inventive powers.

Even when wealth and fame were his, the constant worry of legal action caused him to comment that his only pleasures in life were idleness and sleep. Watt died in 1819 at Heathfield, near Birmingham. He had given power to mankind—a power which he imagined would bring not only wealth but happiness to common people. Probably he felt more acutely than most the tragedy created by the greed of men who made his engine the master of those who worked with it, instead of their servant. It was not the fault of James Watt that the triumph was spoiled by the misery of the towns, where the noise of the engine went on hour after hour and human beings were sacrificed to serve it.

4

THE SMOKE THAT BURNS

DISCOVERY OF COAL GAS

FEW people who have founded a great industry have also been honoured as the reincarnation of a god, but this is one of the many notable facts about William Murdock (he himself altered the spelling of his name from Murdoch because he disliked the soft sound which English people gave it). When Nasef-ed-Din, Shah of Persia and King of Kings, visited Britain in 1873 the gas lighting seemed to impress him more than any other feature of Occidental civilisation, and he demanded to know the name of the magician who had first harnessed this phenomenon. When he was told that it was the invention of a Scotsman named Murdock, he announced that the man was clearly a reincarnation of Merdoch, god of light of Persia, Babylon, and Assyria. When the Shah returned to his kingdom, he took with him several portraits of Murdock to hang in the palaces and temples of Persia, and even to-day there is a sect in that country which worships the nineteenth-century Murdock instead of the Merdoch of prehistoric times.

The lights of London which impressed the Shah in 1873 had developed from the invention then more than eighty years old, for it was in 1792 that Murdock first illuminated his home in Cross Street, Redruth, Cornwall, with gas produced by "cooking" coal. The event is of such importance that Murdock's name has become inevitably linked with gas, though in the eighty-five years of his busy and resourceful life he could well be known as an inventor in many other industries born or expanding at the time. Although his fellow-countrymen seem strangely shy about making this man's fame known

18 A reconstruction of the scene when gaslight shone from Murdock's cottage in Cornwall in 1792.

far and wide, he could well rank as one of Scotland's finest sons and take his place high among the honoured lists of engineers and poets, scientists and authors with whom Scotland has been so richly endowed. Maybe they felt a little regretful that Murdock, like so many other boys of his era and since, tramped southwards across the Border in search of fame and fortune. It was in England that he found the niche which he filled so well, and his own country was the loser by it.

He was born at Bell-o-mill, Old Cumnock, Ayrshire, in 1754. A charming story is told locally which states he cooked coal in his mother's teapot, which seems as unlikely as the similar anecdote about James Watt and his mother's steaming kettle.

For one thing, tea was such a luxury that few ordinary households used it; for another, a teapot was so precious that the most inventive lad would have repressed the desire to conduct noisome experiments in such a receptacle. What is true is that he made himself a hobby-horse while still at school, built a bridge over a local stream while still a juvenile, and constructed his own lathe. When he was twenty-three he set out for the famous works of Boulton and Watt at Birmingham, where he got a job, partly on the reputation of his father, who had helped Roebuck on Watt's steam engine patents, and also on the strength of his hat.

This piece of headgear was of wood, most beautifully turned on his own lathe. Murdock was promptly engaged at 15*s.* a week, and after two years of experience in the works he was sent to Cornwall, where the firm hoped to sell their steam pumps to the mine-owners. As manager of the concession for the whole area, his basic wage was £1 a week. He easily settled down in a district where Scotsmen were almost as foreign as Negroes, which says a lot for his charm, and he eventually married one of the local lassies to seal the alliance between north and west.

Engineering was his hobby as well as his profession, and his first claim to fame came in 1784, when he completed a model steam locomotive, after three years' work, which chugged its way along the local street, thereby giving the inhabitants the impression that devices of the Devil were abroad. The fact that this road carriage was on a miniature scale is one reason why it failed to capture the imagination; otherwise the advent of the locomotive might have been advanced by many years.

The manufacture of synthetic dyes, oscillating movements for steam engines, and preservative paints were among the inventions which occupied his spare moments away from the mines; but the making of coal gas was undoubtedly the most important in its practical results. By 1792 he had constructed an enclosed iron cauldron in the garden of his Redruth house, with a pipe leading into the room he used for his work; and this provided a light above his bench and desk. Its success encouraged him to extend the pipes to other rooms until gas on tap was available in every room. Another ingenious device he made was a leather case connected to an iron pipe which could be used as a portable gas torch, and his quixotic sense of humour led him to terrify the local inhabitants by squeezing the leather so that a yard-long tongue of flame shot out of the burner. Such a sight in the mists at evening on the Cornish moors must have been an eerie one, and certainly added to the reputation for magical matters which this remarkable Scotsman had earned for himself in his self-imposed exile.

The perfection of his private gas plant occupied two years, and by 1794 he was convinced that large-scale commercial development was within the bounds of possibility. His employers, Boulton and Watt, might have gained all rights by taking out a patent, but as they were at the time deep in legislation, which proved both costly and disappointing, as regards their own steam engines, they refused to launch into fresh adventures of this nature. This lack of interest exasperated Murdock, who for a time returned to Scotland, but by 1798 he had been persuaded to return to active work with Boulton and Watt, this time in the important and responsible position of manager of the Birmingham factory and at a salary of £1,000 a year. The attitude of the firm entirely changed, and a special department was devoted to making gas plant, while a large area of the factory was illuminated by gas. The Peace of Amiens of 1802 was marked by a celebration at which the exterior of the Soho works was illuminated by gas, and this was almost certainly the first public exhibition of manufactured gas lighting in the world.

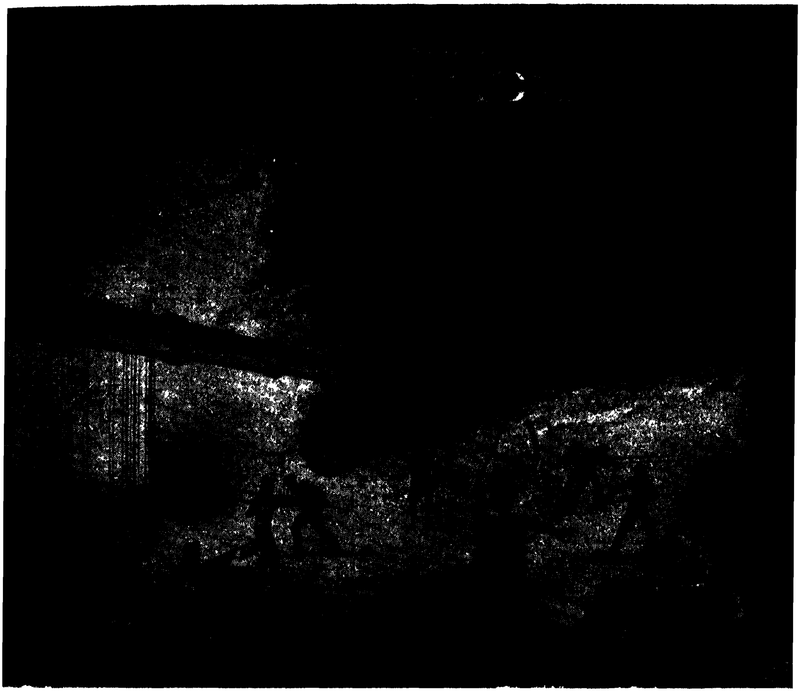
Natural gas lighting was already quite familiar. In Shropshire, for example, many years before, an enterprising cottager who found an escape of natural gas in the garden built a small hut over the seam, and charged 1*d.* for the peep show, and in 1765 the Speddings, who ran large coal-mines belonging to the Lonsdale family at Whitehaven, got rid of the huge quantities of natural gas in the workings by drawing it off and lighting the offices and some of the mine's galleries with it. The idea was so successful that they proposed to supply lamps throughout the town—a proposition which the authorities turned down as dangerous. It was indeed " playing with fire ", and in the three years the supply lasted it must have been more by good fortune than anything else that no severe explosion occurred.

Such ideas on a smaller scale were gaining ground all over Europe, and some scientists were certainly trying to manufacture gas at the same time as Murdock, though with less success. Notable among these was the Frenchman Lebon, who worked with wood and charcoal, and a German named Winsor, while George Dixon had experimented in cooking coal coal to produce gas as early as 1760.

But this work was still on a laboratory basis when Murdock was already lighting factories with gas. In 1803 the whole of the Soho plant was so lighted, and a year later Murdock had started an installation for the large factory of the cotton-spinning firm of Phillips and Lee in Manchester. It was completed two years later.

Official science was by now recognising the importance of Murdock's work. In 1808 the Royal Society listened to a paper by him, and for this he was presented with a gold medal. The ceremony gave point to Murdock's pioneer work, and helped to refute the claims of the German Winsor, who had by then arrived in London. This man was a peculiar personality, and at this date it is not possible to analyse the genuine features of his character. He undoubtedly had a good technical knowledge of the properties of gas, but his flair was in the exploitation of its commercial possibilities. He visited England and saw that gas would soon be a common utility service, and his sense of showmanship resulted in a special display in Pall Mall on 4 June 1805 to mark the King's birthday. It may well be imagined that this display caused much more comment than that of Murdock in 1802, and crowds packed the street the whole evening.

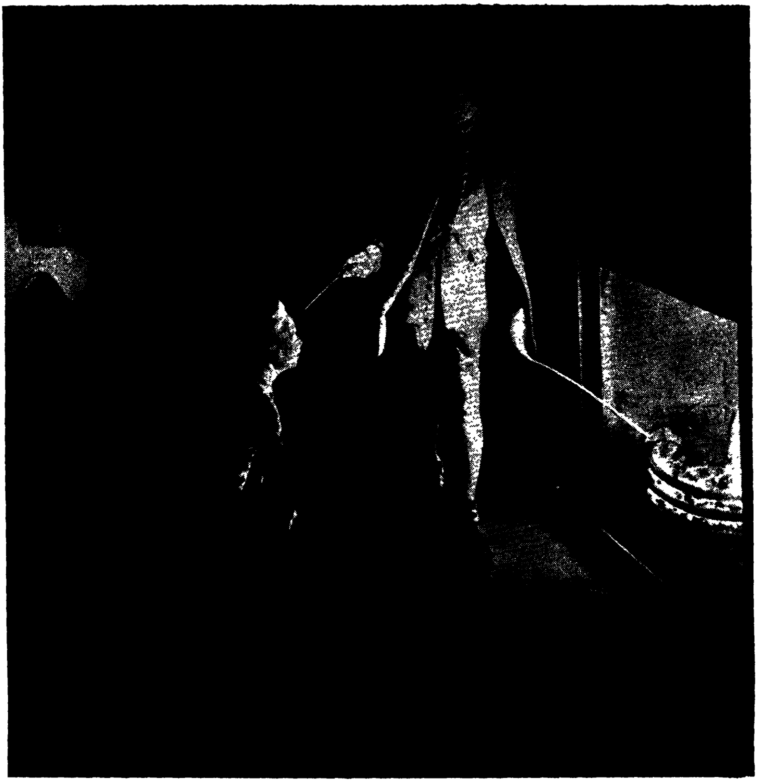
Winsor was after fortune rather than fame, and in 1807 he floated a company with a projected capital of a million pounds. Apart from donating a matter of £10¾ millions



A contemporary artist's impression of the scene at the gas works in Brick Lane, London 1821.

annually to the Government, Winsor estimated he could pay some £5,500 a year interest on each £50 share. The proposition was, of course, as wild as an imaginative brain could conceive, and it totally ignored Murdock's contribution to the new industry. There was some controversy in Parliament about this, but the mere fact that Murdock had failed to patent any part of his process made legal action impossible. Winsor's idea for a company (in a more realistic form) went ahead, and in 1812 the Gas Light and Coke Company, which flourished until nationalisation, was founded.

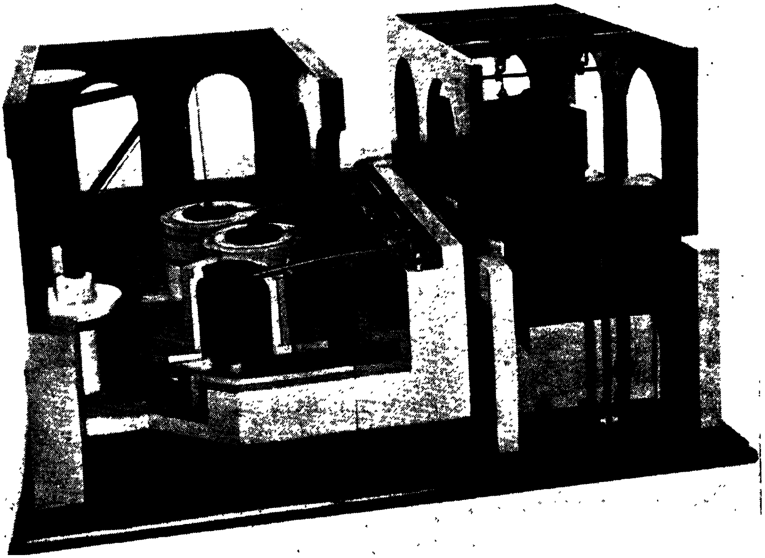
William Murdock lived until 1839, continuing to work at Birmingham on general engineering matters, and by then gas had become available in the majority of the large towns of the country, with millions of pounds of capital involved. The progress in gas manufacture which followed was largely the work of Samuel Clegg, an assistant to Murdock, and probably



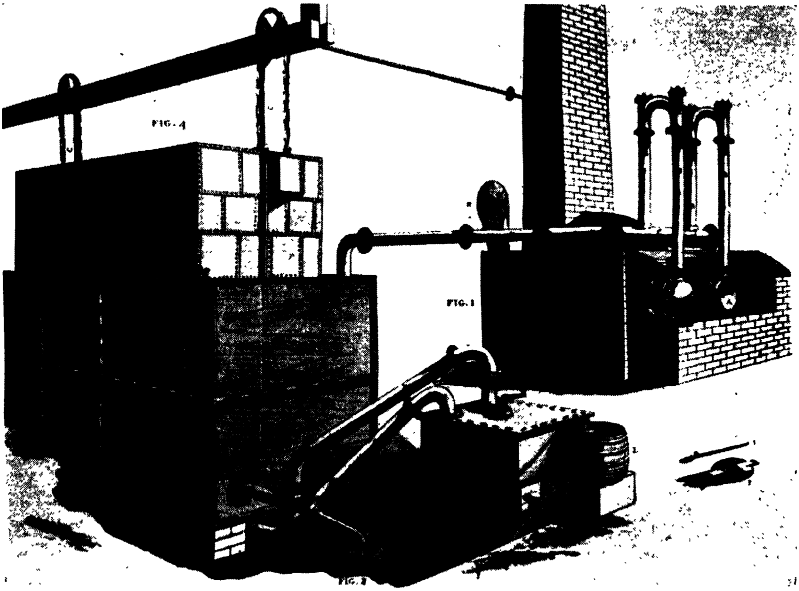
20 George Dixon experimented with gas in 1765: a Science Museum reconstruction of the scene in his home.

the world's first specialist gas engineer. Purification of gas with lime (first used at Stonyhurst College in 1811), the gas meter, and an improved burner are among his contributions to the industry. He was the engineer who put up the first gas lamp on Westminster Bridge and in the Guildhall of the City of London. He installed gas plants at Birmingham, Bristol, and Chester.

In many cities several companies competed for the supply contracts. Five different plants sent gas into the West End of London a century ago, and in Westminster three mains were available in many of the chief thoroughfares, such as Cockspur Street. But the most unusual of these early enterprises was undoubtedly the Manchester organisation run by



21 A model of Murdock's gas plant in use by 1805.



22 Part of an instructional diagram of a gas-making installation in 1812.

the local police. It began as a single light over the police station and spread in the eighteen-thirties to a wide area of the town. Although it does not seem to have been appreciated as such at the time, the Manchester police enterprise was the forerunner of a public concern run by a public authority for general benefit rather than private profit.

The police in every part of the country were enthusiastic supporters of gas manufacture, for no other invention of the time had such a marked effect on the prevention of crime. In London, the fact that the gas-lit streets coincided with the formation of a police force meant that for the first time for many a year night was no longer a period of danger for the pedestrian abroad in the caverns between the buildings of the Metropolis, where criminals were the rule rather than the exception.

The story of William Murdock is the story of the discovery of gas, one of the greatest examples of the provision of heat, power, and light on tap, and it is regrettable that few tangible gestures of gratitude have been accorded to his memory. An obelisk in his boyhood home, a bust in Scotland's Hall of Heroes, and a tablet near the site of the now demolished house in Redruth are the total of our regard for him, unless the more imaginative may feel his real memorials are in the towering gasometers, the great gas furnaces of industry, and the comforting fires of our homes, where the flame from smoke burns in the service of mankind.

No one should imagine for an instant that coal gas will gradually give way to other forms of heat and power. It is cheap to produce, and with new methods of production an even more widespread use than in the past is possible. Great areas of our coal-fields are not worth mining because the quality of the coal is poor or the seams are thin and awkwardly placed. Such coal can be turned into gas where it lies. This idea has been successfully used in the Soviet Union and America for some years, but the original suggestion and method came from the brain of Sir William Ramsay in 1912. At that time Britain was reaching her greatest output of mined coal before or since, and the idea did not seem worth the trouble, even though it used more than 80 per cent. of the total coal deposits in the area, as compared with 60 per cent. by normal mining methods. To-day, of course, the situation is very different, and at the time of writing a national survey is going on for seams which could be worked in this way. Underground gasification of coal is already in progress at Newman Spinney, near Chesterfield. All that is needed is to bore two narrow vertical shafts into the seam. An incendiary bomb is dropped down to start the coal burning, and air is pumped in to create a draught. The gas emerges from the other shaft, and though it is, comparatively speaking, of poor quality it can provide the cheapest known source of motive power with the exception of water power for electric generators built alongside the shaft. Synthetic chemicals can, of course, be extracted just as is the case with the more conventional type of gas-works.

This modern method of making gas from coal is in many ways a swing of the pendulum. As we have seen, early experiments with gas took place where there was a natural source of it from the earth. To make gas from hard coal was a difficult and intricate process, and for a time at least many advocates of gas suggested that it could be the more easily manufactured from oil. Coal gas won the day, for the simple reason that large supplies of mineral oil had not been tapped. The discovery of the method of distillation of crude oil into an illuminating as well as a heavy slow-burning liquid was another British triumph which followed very soon after the use of coal gas had become fairly widespread.

5

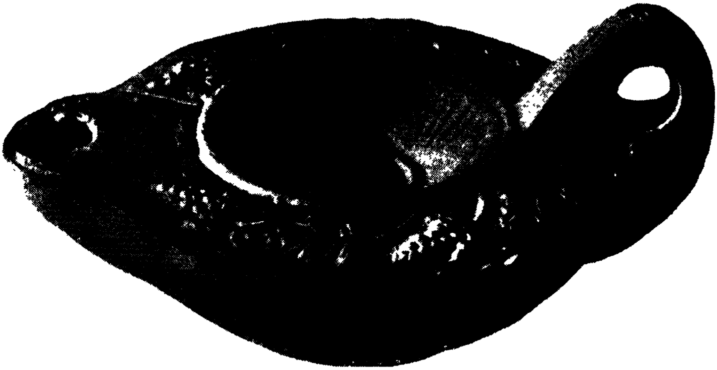
PRECIOUS STREAM

THE STORY OF OIL

IF modern civilisation depends for its progress on the wheel, it is certainly true that the wheel depends on oil. Without that precious substance, much of the power to drive it and most of the lubricants to keep it spinning would be missing. Yet the oil industry is only a little more than a century old. Since 1847 it has grown to its present gigantic size, a major weapon in negotiations between nation and nation, a target for war operations, and the means of making the greatest individual fortunes which man has ever known.

Oil is still something of a mystery to geologists. They have squabbled for the hundred years it has been commercialised about its origin. Most experts now agree that petroleum was formed from organic remains which accumulated on the sea floor, though in some remarkable manner the substances thus accumulating lost their oxygen, so that the resultant petroleum consists of hydro-carbons, compounds of carbon, and hydrogen. The oxygen was destroyed either by bacterial action or by radio-activity from the rocks which surrounded the lakes of decaying matter. When the evolutionary oil process is understood, it may be possible for man to manufacture petroleum and lubricants for himself: a problem which succeeding generations will have to face, because the present consumption of oil will drain all known natural supplies within the next hundred years unless some of the reputed sources under the world's oceans are capable of being tapped. The untested sedimentary basins of the globe's surface are far larger than those already exploited.

Man has known about the existence of petroleum for many thousands of years. In the Middle East natural springs were



23 A Roman oil lamp.

so common that the discovery of the inflammable qualities of the treacly liquid was inevitable, and it is believed that crude methods of distillation were used, particularly by the priests, who were thereby able to produce magical results of creating fire with " water " and so on. A more practical use was for caulking ships, waterproofing earthenware pots, and even embalming bodies. Some walls in the ruins of Persia also show traces of a tarry paint which indicates that buildings were either weatherproofed with natural oil or even mortared with this substance.

The word for " oil " in the Sumerian language indicates a form of naphtha. The Biblical translation of the ancient Hebrew word for oil is " slime ", and in Genesis there is a reference to the fact that the Vale of Siddim is full of slime pits. Marco Polo reported on the oil wells at Baku on the Caspian Sea, commenting that the oil, though not good to eat, was useful for burning. He also showed that petroleum jelly, now such a normal form of ointment, was used by the natives of the Caspian area to cure the mange of camels.

But not until 1847 did the first direct investigation of the properties of oil take place. In that year James Oakes, an ironmaster of the little village of Riddings in Derbyshire, was prospecting for iron ore and coal, and uncovered an underground pool of thick, black liquid. Oakes mentioned his find to his brother-in-law, who was later Lord Playfair. He in turn wrote to a friend, James Young, a scientist and engineer. The letter, which marks the birth of the world's oil industry, has been preserved :

> MY DEAR YOUNG,—You know the mineral naphtha [oil] is a rare natural product, no spring of it occurring in this country, all being imported from the Continent or Persia. Lately a spring of this valuable product has been discovered on an estate belonging to my brother-in-law, Mr. Oakes, near Alfreton, Derbyshire. It yields at present about 300 gallons daily.
>
> The naphtha is about the consistency of thin treacle, and with one distillation it gives a clear, colourless liquid of brilliant illuminating power. It dissolves caoutchouc [*rubber*] easily. My brother intends to set up stills for it ; but as they are ironmasters, this would be a separate industry, so I have advised them, if possible, to sell the naphtha in the crude state to chemical manufacturers, and thus avoid carrying on an industry foreign to their occupation. Does this possibly come within the province of your works ? If it does, I will send you a gallon for examination. Perhaps you could make a capital thing out of this industry and enable my friends to do the same. You are aware that naphtha is now largely used for adding to the illuminating power of gas, and that the tar residue is a valuable product.

James Young was immediately interested. Within a few months he had set up a small refinery which produced a light oil for illumination and a heavy oil for lubrication. He was not, however, satisfied with his refining process, which sometimes yielded a liquid which was clouded and turgid. He wrote to Playfair about it, who identified it as a rare substance known as paraffin. With a sample of it, Playfair made a couple of candles, and these burned brightly on the rostrum when he delivered a lecture at the Royal Institution on " Petroleum and Its Products ".

Those two spears of white, almost smokeless light were a beacon on the path of progress, however tiny and insignificant they may appear to us. It must be realised that, apart from the towns where Murdock's gas lighting was now available, the problem of illumination was a formidable one. The majority of people throughout the world worked by the light of day, and when winter came and the mornings and evenings were dark, work ceased. Steady production throughout the year was impossible, and outside the homes of the rich, any social or educational activity which would in itself enhance the progress of civilisation had at best to be severely restricted by the supplies of illuminants, and at worst done away with altogether because no source of light beyond that from a peat or charcoal fire was available.

To a modern world, accustomed to light at the flick of a switch, the worries of the onset of winter to the average family before the early years of the nineteenth century can hardly be imagined. Tallow, an animal fat, was the principal source of light from the fifth century to the Napoleonic Wars. Monasteries, where many beehives were kept, could afford beeswax candles on special days, and churches in later years tried to make a special display on such winter festivals as Candlemas and Christmas. For the country folk the sight of several candles burning at once was indeed something to remember. In their own homes they had rushlights, made in autumn by dipping osiers in fat. A rushlight 2 feet long would burn for an hour, and fortunate indeed were the people who could find enough fat to make sufficient rushlights to give a couple of hours' light through the winter evenings. In the eighteenth century these rushlights could be bought from street vendors at the rate of eleven for a farthing ; cheap enough—but still a luxury for people earning a few shillings a week.

In that century candles became more common. One giving a couple of hours' light could be bought for a halfpenny. The huge chandeliers hung in the houses of the rich at this time were very costly to keep alight. The poor people could not afford the new type of candles, which were made from whale oil. They still relied on tallow candles, which had the additional quality that, when times were hard, they could be eaten. This edibility brought its own problems. For example, the lighthouse-keepers were in constant trouble for eating the candles supplied to them for their work. In some parts of the country local sources of vegetable and animal oils were fairly easily obtained. In Scotland resinous pine was used, and around the coast fish-eating birds were valued. Until the present century the people of the Shetland Isles were still using the device of a wick threaded through a dead stormy petrel.

The Playfair candle changed the situation entirely. When the lecture was given the price of tallow candles was 6*d.* per pound, and sperm oil candles 1*s.* 11*d.* per pound. As soon as paraffin wax became plentiful, these prices dropped considerably. More important, the paraffin oil lamp, giving an unbelievable level of pure white light, made its appearance, though it was not common until after the discovery of the Pennsylvanian oil-fields in 1859, when on an August afternoon Colonel Edwin Drake struck oil at a depth of 69 feet.

Long before this time the small source of petroleum at Riddings had dried up. In its brief life the daily yield was about 300 gallons. Young turned to the problem of distilling oil from coal. With a very rich cannel coal known as Boghead, he managed to produce a fair yield until the supply of this coal was exhausted. Thereafter, in the eighteen-sixties, he worked on refining shale oil, which resulted in a vast expansion of the shale oil industry in Scotland.

His distillation system founded a very profitable business, and the Scottish oil-shale industry expanded steadily until, in the years before the First World War, annual production had reached 3½ million tons of shale. The tremendous rise in production of overseas oil wells almost caused the extinction of the trade because of the higher cost of extraction until the Government granted a tax relief on home-produced oil.

To-day the British oil-shale mining is steadily expanding,

24 At work on the excavation of one of Scotland's hidden treasures: oil shale.

and the discovery of a shale field covering about 200 square miles in extent, stretching towards Airdrie from the Lothians, will give further impetus to the process discovered by James " Paraffin " Young.

Few people realize that, in 1951 and before the opening up of the new field, British oil shale production was employing about 4,000 people and was producing 1½ million tons of shale per annum. Apart from its major contribution to the petroleum requirements of the nation, this Scottish shale provides material for a variety of by-products, including wax, high-grade coke, sulphate of ammonia, and the main ingredient for a household detergent. One obstacle about the newly-discovered shale deposits is that they lie between 2,000 and 4,000 feet below the surface, the larger figure being 1,000 feet more than the deepest coal-mine. For this reason experiments are being made to discover a way of extracting the oil from the shale underground by electric heat.

The little pool at Riddings inaugurated the Oil Age ; the shale deposits of the Lothians may help to solve our problem of fuel supplies in the future and it may well be that electricity provides the key with which to do it. Such an event will be an excellent example of the way electrical power has become a fundamental source of controlled energy in every industry. The story of the way this mysterious, invisible force was investigated and made to provide yet another source of power for mankind can appropriately follow.

6

THE VITAL SPARK

EARLY INVESTIGATORS OF ELECTRICITY

THE existence of electricity was known, if not investigated, several centuries B.C. In Syria women using distaffs constructed from amber knew that the revolving spindle, if it touched their clothes, would attract them strongly ; this was a primitive dynamo. This curious property of amber, an important trading commodity of the Mediterranean nations, was well known to the philosophers and sages of the pre-Christian era. Thales in the sixth century B.C., following the precepts of his Greek religion in putting divine entities into streams, trees, and so on, gave it as his opinion that amber had a soul. Theophrastus, 300 years later, wondered whether the attractive power of amber was an integral part of the substance or whether amber was merely a channel for an invisible fluid. He cast around to see if other substances worked in the same way. He found that one did, a mineral called tourmaline. Aristotle, whose enquiring mind probed into the mysteries of every living thing, recorded the phenomenon of a fish which was able to benumb its victims by an unknown power which was not visible as a physical action.

This information was laid aside, with the exception of some investigations into magnets by a thirteenth-century seer named Peregrinus of Picardy, for 1,500 years after the Birth of Christ, but was safely stored in the works of Aristotle and Pliny. Both authors must have been known to William Gilbert, a Colchester scholar, who is regarded as the father of applied electrical science. Born in 1540, and dying in 1603, Gilbert's life covered one of the most momentous periods in English history. If Elizabeth's Court could have but known, the amusing experiments which Gilbert gave were in their way as important as the news of the defeat of the Armada, the success of Mister Shakespeare's new play, or of explorations in the New World.

Gilbert was appointed personal physician to Queen Elizabeth. It is said that his job was not always of the easiest, for his neurotic mistress badgered him for elixirs which would give her back her youth more effectively than the cosmetics she used so crudely. But Gilbert had the placid mind of the true investigator, and apart from carrying out his medical duties as best his knowledge would allow, he spent much time on science. Starting with the amber mentioned in his Greek and Latin books, he tested innumerable other substances for the same property, suspending a needle on a piece of silk near them to see if they attracted it after friction had been applied. Rock salt, sulphur, and resin were found to have the property, and Gilbert also made the needle move with his royal mistress's gems and sealing wax. There is a source of pleasing imagery in the thought that a diamond looted by the roystering Drake and the wax used for the Queen's orders to her admirals helped to form the foundations of electrical science.

Gilbert adopted the Greek word for amber, *elektron*, to describe any substance which had the same property of attraction, and before his death set down a list of them, heading it " Electrics ". He also wrote a treatise, *De Magnete*, in which he likened magnetism to a type of gravity which he described as an " effluvia of souls " moving in an ether.

A few years passed after Gilbert's death without any further progress being made. Then Robert Boyle, born in Munster, Ireland, in 1627, developed Gilbert's findings. Boyle, discoverer of the air pump on which his famous Law was based, was a brilliant scientific observer and a fine mathematician. He was the son of the Earl of Cork. He noted that when Gilbert's substances were rubbed the force remained latent for some time afterwards. It was a vitally important effect which Gilbert had missed ; it meant that this new invisible power could be stored. Boyle's reputation in the scientific world of the seventeenth century was great, and the news that

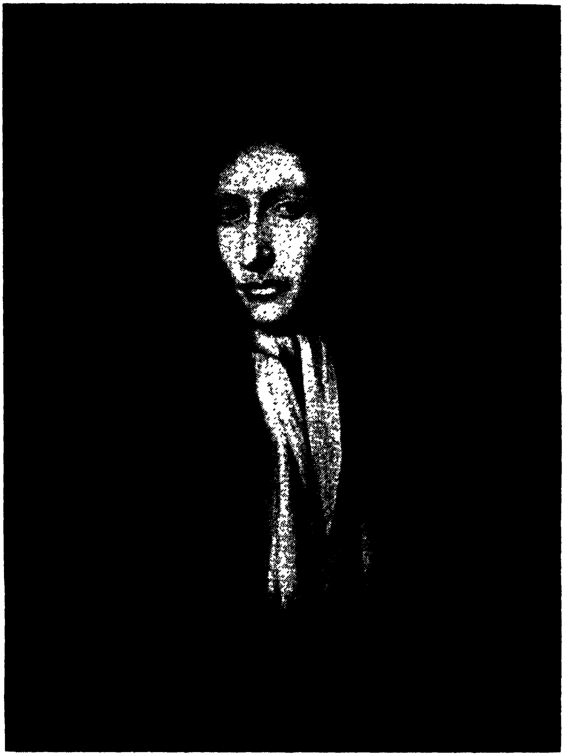
25 William Gilbert demonstrates the powers of magnetism to Queen Elizabeth.

he was interesting himself in electricity caused scholars all over Europe also to devote themselves to the science. Five years before Boyle's death, the sixty-one-year-old Mayor of Magdeburg, Otto von Guericke, visited England and met the Irish scientist. After his return he caused a revolving ball of sulphur to glow slightly when a hand was placed near it. He also showed that electricity consisted of two forces, one which attracted and one which repelled, and that a substance which had been electrified had the power to electrify another one without the application of friction.

The story returns to Britain. Francis Hauksbee, about the beginning of the eighteenth century, improved the von Guericke machine by using a glass globe instead of sulphur. He drew the attention of members of the Royal Society to the similarity to lightning of the sparks which flashed between the revolving machine and his hand. He suggested that the power seemed to be the very soul of matter, and in saying it, gave man the first glimpse into the universe hidden within an atom of energy. Shortly after Hauksbee's death about 1713, Stephen Gray made a practical advance by the discovery of conductors and insulators. Gray was a Bluecoat boy, and his experiments brought their notable results in 1729. His apparatus was simple. An ivory ball enclosed in a sealed glass tube was shown to gain attractive power for tiny slips of paper whenever the exterior of the glass tube was rubbed. He experimented with links of many kinds and found that silk was a non-conductor and that pack-thread was a conductor. Suspending a line of pack-thred some 800 feet in length by loops of silk, he sent an impulse of electricity along it.

With the knowledge of conductors available, the possibility of storing electricity was the next problem to solve. A professor of Leyden named Musschenbroek was the first to achieve it, and the improvement of the Leyden jar was the work of an Englishman, William Watson. Born in 1715 to a poor London tradesman, Watson was apprenticed to an apothecary and quickly achieved commercial success, amassing a considerable fortune. He did so with one objective : to devote himself to science. He lined a Leyden jar with tinfoil and used strips of the material to carry the current from one jar to another, thereby increasing the voltage of the current. There is one report that he had two miles of wire made and gave his assistant a healthy shock with them, showing that the current travelled instantaneously by using watches to record the time when the wires were connected to the jars and the assistant abruptly dropped the ends he was holding. Watson followed this with many spectacular experiments, revealing the resources of power in electricity which had not been suspected by his predecessors. He electrified a piece of ice so that a glass of spirits blazed up when the splinter was dropped in the liquid, and he detonated gunpowder by remote control. There were many now realising that undreamed-of power was available in this invisible force which had hitherto made puny sparks and tingled on the fingers of the experimenters.

The investigation of electricity expanded to an international scale. In America Franklin and in Italy Volta and Galvani now shared the honours with British colleagues with



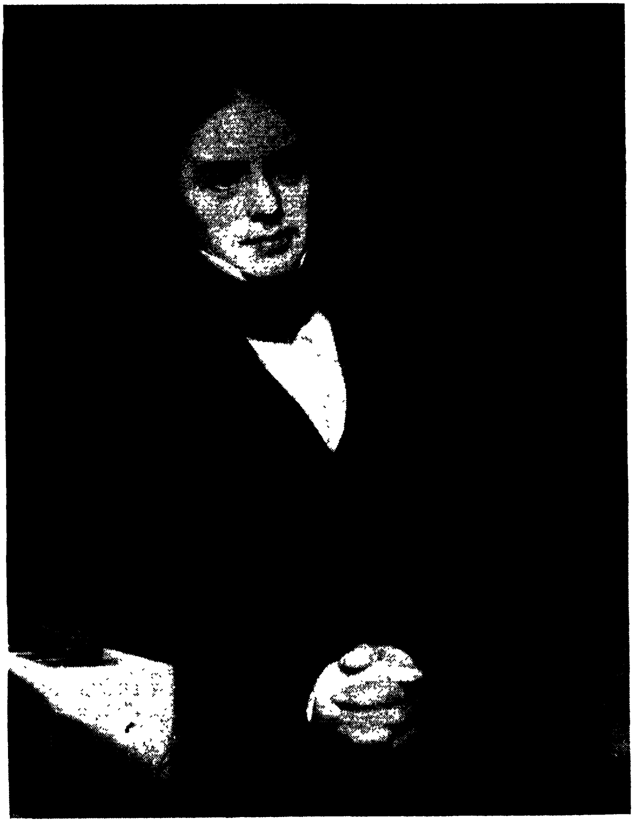
26 Robert Boyle, seventeenth century savant and scientific observer.

important developments. Britain still maintained her reputation with more and more discoveries and inventions. A Stroud schoolmaster, John Canton, manufactured the first artificial magnets, and the eccentric Henry Cavendish worked on the theoretical side. Born at Nice in 1731, Cavendish inherited a vast fortune as a member of the Devonshire family, and his house in London was one of the most magnificent in that famous age of urban residential architecture. Yet there were no house parties or receptions during his lifetime. He suffered from a sense of shyness which was almost a mania. Strangers never saw him, and he rarely went out of doors. A few trusted male servants attended his wants, but the female staff only knew of his presence by the notes of instructions they would find lying about in the empty rooms. Shut away like the alchemists of old, this aristocratic hermit pursued his one great passion : scientific investigation. His calculations on conductors were of direct benefit in showing how current could best be distributed. His success in exploding oxygen and hydrogen electrically in order to produce water was the first event in atomic science, and it is appropriate that the laboratory at Cambridge where the atom was split more than a century later should bear his name.

Before Cavendish died in 1810 he saw his work being ably carried on by Davy, whose experiments with electric light are described elsewhere, though the coming genius of Faraday had not at that time shown itself.

Michael Faraday was born in 1791 in the heart of a London slum, the son of an ailing blacksmith who made a living shoeing cart-horses and mending pots and pans. There were three other children, and for most of his early life young Michael rarely knew what it was like to have enough to eat. At twelve years of age he got a job as an errand-boy to a bookseller named Riebau, who was a kindly man and made the youngster an apprentice in his bookbinding shop without a fee. Riebau's business concerned buying up remainders of unbound books, putting them in special bindings, and selling them. A side-line was the binding of customers' magazines and private documents. From all this material Faraday gained a good education, for he used to read every line of print that passed through his hands. When the customers came to collect their orders, Faraday used to badger them with questions. Many of the books were concerned with scientific monographs or were records of scientific lectures. Their owners became amazed at the youngster's knowledge. One of them gave the boy a ticket to a course of four lectures by Sir Humphry Davy. " He's a great man—perhaps the greatest in England ", he said. " Go and listen to him."

Davy's lectures at the Royal Institution were both scientific and social occasions. The man who demonstrated " laughing

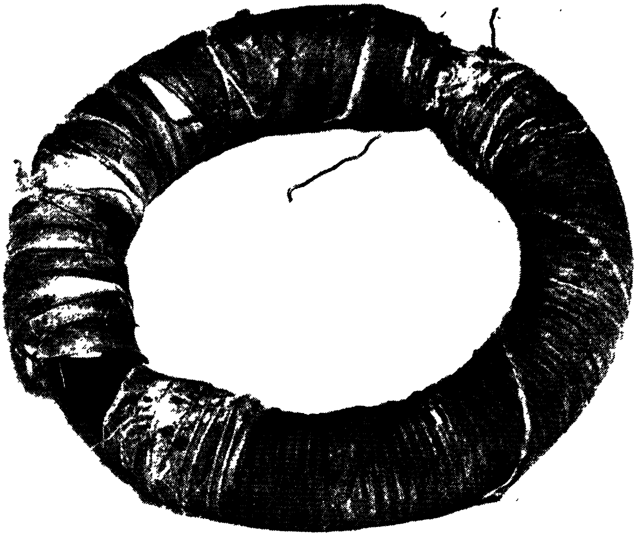


27 Michael Faraday, founder of the electrical engineering industry.

gas" and the relation of the mysterious force of electricity to chemistry could draw audiences of 500 people or more. Many came for the wonder of it, and their interest was superficial. Not so in the case of Michael Faraday. He jotted down everything the scientist said, sketched every experiment, and copied every diagram that was displayed. When he got home that night he wrote them all down, and because he was worried about some points he sent them to Davy for correction. The chemist was amazed to find his remarks reproduced almost word for word. He imagined that his unknown correspondent must be a man of considerable scientific prowess whom by some accident he had not heard of nor met in scientific circles. He asked Mr. Faraday to come to his rooms at the Royal Institution for a meeting.

The surprise at seeing a rather shabby youth in his study a few days later can be imagined. The meeting went on for hours and a friendship developed, so that when he was twenty-two Faraday was offered a job in Davy's laboratory at 25s. a week. The delay was inevitable because there were no vacancies earlier, but Davy had in the meantime planned a scheme which would enable his brilliant but self-educated assistant to talk to the finest scientific brains in the world. Shortly after Faraday joined the laboratory, Davy told him to get ready to travel to every important university in Europe. On this lecture tour the young assistant of Europe's leading scientist was treated as an equal by the savants of every university at which they stopped, though privately he had a hard time, for Davy's wife was intensely jealous of her husband's affection for his protégé, and she insisted that Faraday live as a servant with the grooms and perform the duties of a valet. Despite this insulting atmosphere, of which Davy was quite ignorant, the life was an education that no money could have bought, and the diary which Faraday meticulously kept indicates how carefully he assimilated knowledge. Incidentally, the Continent through which they travelled was in the turmoil of the Napoleonic Wars at the time. It meant little to the two Englishmen nor, indeed, to the scientists whom they met. Faraday himself comments on the sensational news that Napoleon had escaped from Elba : "Being no politician, I did not trouble myself about it."

Before he was thirty, Faraday was a famous scientist in his own right. As a consultant on chemistry, he earned an income said to be about £1,000 a year, the Royal Society made him a Fellow at the age of thirty-two, and the University of London offered him a professorship. Then he threw up all private work and all tuition in order to devote himself to pure science. The resolve meant that his income would be nil, which did not seem to worry him, but the Royal Society



28 Faraday's iron ring and helix, used in the discovery of magnetic induction.

stepped in, relieving him of every financial worry so that he could devote himself to experiment.

Faraday was the inventor of the electric motor, the transformer, and the dynamo. With a beautifully and delicately constructed model, he showed that with a piece of wire and a magnet he could produce a flicker of movement, sometimes in one and sometimes in the other, by passing an impulse of current. From this experiment came ten years of careful work to prove a theory that he had believed was true ; that one current could produce another current in an entirely separate circuit. The model made to demonstrate this was the first dynamo. When he demonstrated it to a group of friends, showing how the current flowed alternately from one end of a piece of wire and then from the other when it was whirled rapidly in close proximity to a magnet, a woman asked : " What is the use of such knowledge ? "

Faraday, always the gentlest and most courteous of men, smiled, and replied that he could not do more than hope it would have considerable use. " What is the use of a new-born child ? " he added.

Humming quietly to himself as he stood staring into space or gazing steadfastly at some embryo model in his laboratory, Faraday went on to make both theoretical and practical contributions to the new science which are still the framework of all training in electrical engineering. The student of to-day who has gained as much knowledge as Faraday had more than a century ago is well on the way to becoming a skilled electrical engineer, such was the spectacular progress of electrical knowledge during the scientist's lifetime.

His own country and every civilised nation endeavoured to shower honours on the greatest scientific figure of his generation. Faraday politely turned down most of them, including a State pension. He became a beloved figure among children, for he inaugurated the famous Christmas Lectures at the Royal Institution which have delighted schoolboys and schoolgirls ever since, bringing science from the Olympian remoteness of the laboratory to the human, jolly atmosphere of the child's world.

Tragically, in the last months of his life his brain started to give way,the more tragically because the weakening was slight and Faraday himself realised what was happening. He found himself conducting experiments on problems over which he had triumphed years before. At the age of seventy-one he gave his last lecture, and by the direct order of Queen Victoria he was given apartments in the peace of Hampton Court Palace, where maybe his predecessor, Gilbert, had demonstrated his little tricks of magnetism to a Tudor audience. In this historic place Faraday died on 25 August, 1867, seated in his work-chair.

Though his country, rich in coal resources, was tardy in fully exploiting the invisible power of electricity by the means he had bequeathed to her, Michael Faraday's work enabled engineers to create energy wherever wind, water, or fuel of some kind was available. The true Faraday memorial is in the humming generators which night and day release millions of kilowatts of energy for the benefit of man throughout the world.

Faraday had been fortunate in meeting Sir Humphry Davy in his youth. Another great English name in the early history of electrical investigation, James Prescott Joule, is somewhat similarly connected with another great scientist, in this case John Dalton, the Manchester Quaker. Joule was born at Salford in 1818, the son of a brewer. Because of ill-health, he was educated at home until he was fifteen, when he began work in the family business, at the same time receiving private tuition from Dalton. The old man found rich ground for his scientific teachings, and young Joule soon had a workshop-laboratory of his own in his father's house. At nineteen he published a paper on an electric motor he had designed, and he was only twenty-two when his historic work on the production of heat by electricity was published.

The law which bears his name was a remarkable feat for a young man largely self-taught as regards practical experiment, and using mostly home-made equipment, for the only instrument he obtained from outside sources was a thermometer. Nevertheless, he accurately calculated the production of heat by electric current. His work was done merely as a hobby when the day at the brewery was over.

When his father died, Joule and his brother had to devote an increasing amount of time to the family business, until, in 1854, when Joule's wife died, it was sold. Thereafter he withdrew almost entirely into scientific research, mainly on the measurement of work done and heat produced by various actions, such as compression of air, friction in water, and in various electrical devices. In 1872 his health broke down and in 1878 he was granted a civil pension. He died at Salford in the same year.

7

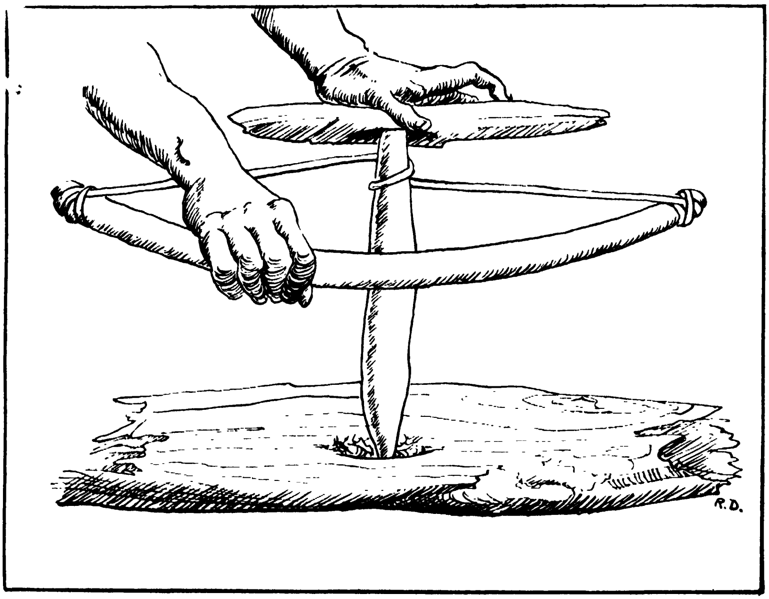
MECHANICAL HANDS

DEVELOPMENT OF MACHINE TOOLS

MAN is a puny animal. Yet with the modest strength of his muscles and the intricate manipulation of his hands he has built on a scale to rival Nature herself. From the delicate wheels of a wrist watch to the massive girders of a Forth Bridge he has learned the secret of fashioning substances just as he wants them. Fire was one ally ; another was the tool.

The primitive hunter who wielded a bone club and the twentieth-century girl who controls a power lathe shearing steel to an accuracy of thousandths of an inch are alike in that both know the way to increase their strength by the use of a lever. For thousands upon thousands of years our tools remained quite primitive. The hammer, the knife, the saw, the axe, and the file were the weapons with which the pioneers of engineering fashioned the metals they had to cut and twist, bend and pierce for their machines. It demanded great skill—sometimes superhuman skill—and the necessary accuracy and strength could not always be produced with the tools available. Machines were needed to make machines. To-day unskilled youths and girls can turn out precision parts after a few weeks' training. Strength is important ; skill needs to be only at a standard of common sense. The ever-restricted supply of skilled craftsmen can be used in the manufacture of the machines to make the machines, and the bulk of the industrial population can create an immensely greater fund of wealth both for itself and the nation as a whole.

The invention of machine tools was forced on the engineers of the Industrial Revolution. Watt, for example, needed cylinders of greater accuracy and strength than hammering, chipping, and filing by hand could provide. And even if workmen could be found to make reasonably good parts, the



29 A primitive bow drill used for making fire and boring holes.

urgent demands of industry for the new machines made the process impossibly slow. Many craftsmen saw that they would be better employed in making tools. A few of them not only became famous tool-makers themselves, but their engineering shops were the nurseries for other tool-makers who paved the way for mass production, where large numbers of similar objects, of a high standard of precision, are turned out by semi-skilled labour.

One of the earliest tool-makers was Joseph Bramah, born at Stainborough, near Barnsley, in 1748. His father was a tenant farmer on the Strafford estate, and Joseph, the eldest of five children, went to work on a farm until he was sixteen. Then in an accident he broke his ankle, and through unskilled treatment he was compelled to take a less active occupation. Accordingly, he was apprenticed to the village carpenter, making farm tools in the day and musical instruments as a hobby at night. At the end of his apprenticeship he took a job in London, where he started his career of invention. At that time the water closet had just been put on sale, and Bramah had a good many installations of this novel refinement to put into the more luxurious homes of the capital. He did not think much of the device, and added an idea of his own which was patented in 1778—the water cock which is the basic principle of the flushing system of to-day. He made a considerable income from this invention, and with the proceeds opened a shop in Piccadilly. Here the principal item on sale was a new kind of lock which he advertised by a notice of a reward of £200 for anyone who could make a device which would pick or open it. The offer was unchallenged until an American locksmith managed to move the lock after sixteen days' hard work some forty years later.

In this lock Bramah had another commercial success on his hands. The demand exceeded the supply. The precision parts of his lock were beyond the skill of most workmen—a dilemma which influenced Bramah to the study of machine tools. Before his most important invention in this field was patented he devised many other machines, including a hydraulic press, a beer pump, and various improvements to the steam engine which got him involved in lawsuits with Boulton and Watt. His planing machine "for producing straight, smooth, and parallel surfaces on wood and other materials requiring truth" was patented in 1802. He used the machine in his own workshops, and later added methods of turning spherical surfaces, either concave or convex, and for cutting concentric shells. With a reputation for accuracy and speed of production far ahead of any engineering works relying solely on the skill of the employees, Bramah's Pimlico workshops prospered steadily, and, perhaps more important, they were the training ground for many other inventors of machine tools both before and after the pioneer's death in 1814.

One of these successors to Bramah was Henry Maudslay, the son of a soldier who was given a job in Woolwich Arsenal after his discharge through wounds from the Army. Henry was born in a house just outside the Arsenal in 1771, and by the time he was twelve he was inside, working as a powder monkey in making and filling cartridges. At eighteen he was a skilled blacksmith, his ability known far and wide beyond the Arsenal, and it was this reputation which influenced Bramah to ask his advice in the manufacturing of his lock parts. Undoubtedly Bramah's idea was to persuade the youth to leave Government employment, and this he managed to do at their first meeting.

Maudslay had not served the normal seven years' engineers' apprenticeship, but he was taken on as a regular hand in Bramah's works, and in a very short time was appointed (by the unanimous vote of the other men) head foreman, which says much for his charm. This quality, by the way, also impressed Bramah's housemaid, who married him in the week he became foreman !

Maudslay revolutionised production in the works by providing machine tools for almost every process. Undoubtedly the success which came to the Bramah concern was largely the result of Maudslay's production methods, which makes it all the more mysterious why his employer never paid him more than 30s. a week, even though he appointed him manager. Bramah is described by early biographers as a pious and temperate man—great qualities in his time ; but the fact that he was also ill-tempered is shown by his legal actions and vitriolic pamphlets attacking his rivals, and his treatment of Maudslay.

Eventually his manager, beset with the difficulty of maintaining a family on 30s. a week, asked for a rise, failed to get it, and promptly resigned. He scraped together enough money to start a workshop of his own in Wells Street, off Oxford Street, a good many of Bramah's customers coming to support him in his enterprise.

Maudslay's first important machine tool invention was a slide rest. He had made one for use in the Bramah works, but the new version was a great improvement. Its adoption in carpentry and metal shops eradicated imperfections of lathe work where the workman applied and guided his tool by brute strength. Only in the case of a handful of skilled workmen was complete accuracy possible. This applied particularly to working on large pieces of metal, where muscular tiredness resulted in variations towards the end of the job, just when the greatest care needed to be taken. The Maudslay slide rest took all physical labour from the operator. All he had to do was to turn a screw and advance the cutter along the face of the metal or wood.

Maudslay's slide rest was used to produce the tools for one of the first examples of successful mass production in history. The customer was Marc Brunel, father of the builder of the Great Western Railway. Brunel had devised machines to make blocks for sailing ships. These were used in large quantities—a man-of-war needed 1,400 of them—and demanded a high standard of craftsmanship. Every block consisted of a shell, sheaves, and pins, each part having to fit perfectly. Brunel's machines had to be as accurate as the best of the hundreds of block-makers in the dockyards. Maudslay, who had by this time moved from Wells Street to Margaret Street, off Cavendish Square, took six years to make the forty-four machines needed—by far the most intricate job of its kind for a long time afterwards—and in 1808 production began. In a year 160,000 blocks worth £541,000 were produced by ten unskilled men; the same number made by hand required 110 skilled craftsmen.

Another tool-maker who received an important part of his training in the Bramah workshops was Joseph Clement. He was born at Great Ashby, Westmorland, in 1779, the son of a cottage weaver. The older Clement was a remarkable personality—or maybe not so remarkable for his era, when a decent standard of culture and education was quite normal among working people, in contrast to the subsequent decades, when the machines demanded long hours of work from children of five or six years of age and education became impossible.

Clement built his own lathe to turn his bobbins. The room of the cottage where he sat at his loom looked out on a semicircle of beehives which he constructed with glass panels so that he could watch the bees while he worked; birds flew in and out of the door and perched on the loom, and an occasional rabbit hopped inside for the green-stuff always available. On the walls were specimens of innumerable insects, moths, and butterflies caught on journeys with the finished cloth to market, all of them classified to the best of his self-taught knowledge.

Young Joseph was brought up in this pleasant atmosphere, helping his father with the weaving and attending the village school, until the pressure of machine competition on cottage weaving resulted in his being apprenticed to a thatcher and slater. He remained in this work until he was twenty-five, though he had plenty of time in the winter to follow his hobby of metal-working. To help his father, he made him a microscope for examining his insect collection, and for the village band he turned out a variety of musical instruments, including some bagpipes which he played himself. For some of these instruments he needed screws, and these he produced on a lathe of his own making—the forerunner of his most notable contribution to production engineering. There was little scope for his talents in a small village, and Clement left it to take a job in a factory making power looms in Kirkby Stephen at 3*s.* 6*d.* a day, less 8*s.* a week for board and lodging. He soon left there for a larger firm in the same line at Carlisle, and afterwards for Glasgow and Aberdeen. In the last town he was able to earn three guineas a week making screws and other small parts for power looms—a wage which enabled him to save £100 by 1813 and to take the time-honoured route to fame and fortune in London. His ability was such that he was engaged at the first engineering shop he saw after alighting from the stage coach at its terminus at Snow Hill, Smithfield. The pay was poor and on the suggestion of his workmates he applied for a job with Bramah. He remained there until Bramah's death, when he transferred to Maudslay's establishment. When this frugal and ambitious man had saved £500 he launched out on his own in Newington Butts, where he quickly became noted for his mechanical drawings, many of which were executed for the Society of Arts.

Many inventions and improvements for the equipment of lathes followed, but Clement's most important contribution in his field of activity was the standardisation of screw threads in 1828. Before this, every engineer adopted his own pet idea, so that another engineer making a repair had to drill out the hole thread and remake it for his own screw design. He worked out calculations on the basis of length which were soon adopted by the engineering industry, Clement offering them screw-turning lathes of unexampled precision.

Clement, the best precision engineer of his day—he charged more than anybody else for his work and was still overwhelmed with orders—turned out innumerable inventions. A planing machine, fluted taps and dies, and a self-adjusting double-driving centre chuck are indicative of the new fields invaded by machine tools as the result of his work. He never had more than thirty workmen in his shops and never canvassed for orders. Yet the truism that "good wine needs no bush" was never better proved, for this son of Westmorland, who once wrote his name with difficulty and made early prototypes without any drawn plans, received orders from every part of the world. Before he died in 1844 a Clement-trained workman or a Clement-made tool had become the standard by which men and workmanship were judged.

An engineer who gained much of his experience in the Maudslay workshops was Richard Roberts, born in 1789 at Llanymynech on the borders of Shropshire and Merioneth. He went to Maudslay's works while on the run from recruiting sergeants, his name having been drawn for service with the militia. Wisely deciding that London was big enough to hide in, he was given a job by Maudslay, and then set up in business on his own in Deansgate, Manchester. In 1816 he invented a machine tool for correctly sizing wheels, and in the same year he produced an improved screw lathe. A planing machine, refinements to the slide lathe, broaching and slotting machines were other inventions of Roberts.

The main part of his business was the production of cotton machinery, and a self-acting mule was one of his inventions. The works had some profitable sidelines produced with the aid of his machine tools, one of them being iron billiard tables, constructed with perfect surfaces by his planing machine.

In 1848 the contractors building the tubular bridge over the Menai Straits were held up by the slow punching of holes in the iron plates, each of which had to be done by hand. Roberts was asked to help, and he made the Jacquard punching machine, a self-acting tool which punched any number of holes with mathematical accuracy. Roberts produced invention after invention, but he had little inborn business sense. Many of his devices remained unpatented, and though they were to be found in every engineering shop in the country he derived no income from them. His own concern, which built locomotives as well as textile machinery, was a prosperous one, but Roberts was quite unable to save money, and he died in poverty.

A second name to be remembered as one of Maudslay's protégés was Joseph Whitworth, who completed the idea of uniformity of screw threads initiated by Maudslay and Clement, producing the machines to give the necessary accuracy. At the Great Exhibition of 1851 the engineering work of Whitworth proved his point that there were " two great elements in constructive mechanics, namely a true plane and the power of measurement ".

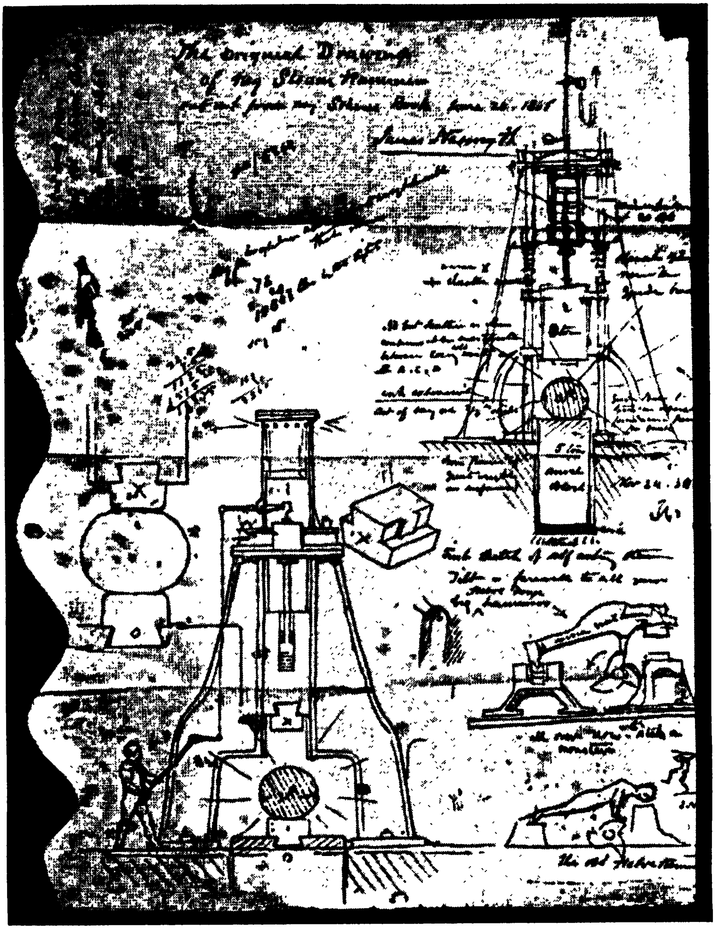
A souvenir of the Exhibition published in 1853, in describing Whitworth's machine exhibits, said :

> His peculiar genius has enabled him to effect such a convenient arrangement of each that his machines are almost self-acting ; leaving nothing for the workman to do but fix his work and keep his tools sharp ; consequently Mr. Whitworth can produce better work by comparatively raw hands than formerly could be done slowly by the most skilful workmen at very high wages.

Whitworth himself gave some figures to show the benefits to engineering and industry generally which resulted from the use of machine tools in lowering production costs. In 1826 the cost of labour for making a surface of cast iron true was 12*s.* a square foot (as a skilled workman's wages at this time were about 35*s.* a week, the time taken in chipping and filing by hand can be gauged) while the planing machines available by 1851 did the same work at a labour cost of less than 1*d.* per square foot.

The Whitworth screw thread is something that everyone can appreciate if he pauses to think for a moment of the benefits it has brought to modern life. If a nut or bolt falls off a bicycle, vacuum-cleaner, motor car, or similar piece of machinery in common use, we rummage in the tool box or call at a hardware shop to find a duplicate part. With the appropriate size discovered, nut will fit bolt exactly, no matter what British engineering firm made it. No great memorials have been erected to mark this advance, and no one pauses to marvel at the efficiency of such a simple piece of standardisation, yet it results in great economies and usefulness. The British Whitworth profile on the screw thread was made on an angle of 55 degrees. Until 1950 this was different from the American angle of 60 degrees, and the discrepancy permits an illustration of the advantages of a standardised thread which is possibly more vivid than that provided by identical threads. The Whitworth thread, apart from the angle, was different from the American design, known as the Sellers' thread (named after its designer, who offered his screw to the American Franklin Institute in 1861). Whitworth's thread was rounded at the top and bottom ; Sellers' was flat at the top and turned into the core of the bolt at a sharp angle.

No one worried particularly about the difference until the Second World War. Then the universal standardisation which the early tool-makers of Britain had advocated was seen as a vital ingredient of military and industrial co-operation. American aircraft flying from Britain could not be serviced with nuts and bolts by British manufacturers. For the 200,000-odd nuts and bolts in a typical bomber no screw-cutting machine in use in Britain could produce a replacement. Similarly, with British-designed engines for American manufacture changes had to be made to use the Sellers' threaded bolts. In guns and tanks, where completed products were of identical appearance whether they were made in Britain or America, no nut or bolt was interchangeable, and in areas where both forces fought side by side immense stocks of spare parts had to be duplicated. The lesson was learned, and both countries agreed to modify their own screw threads to produce a combination acceptable to both countries' engineers. As a result, a British nut can now fit on an American bolt, and if Whitworth's hopes for a world standard have not yet been brought to fruition, the two major industrial nations have at last seen the force of his arguments.



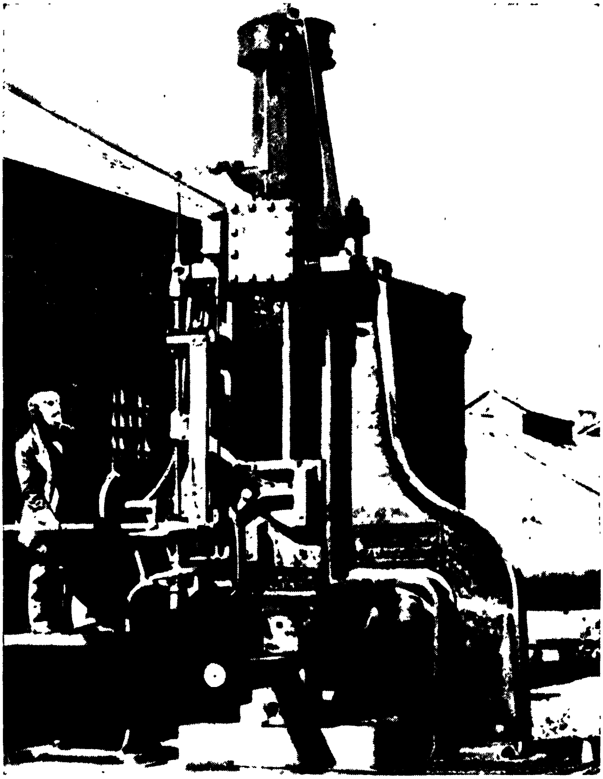
30 The original drawing made by James Nasmyth for his steam hammer.

Most people have heard of the Nasmyth steam hammer. Its inventor was born in Edinburgh in 1808, the youngest son of a well-known landscape painter who made a hobby of mechanics. When young James Nasmyth went to Edinburgh High School, he became friendly with the son of an ironfounder and every Saturday afternoon the boys used to go and make models in the foundry. By the time Nasmyth was fifteen he could work in most metals, and he earned plenty of pocket money making steel-and-tinder boxes and model steam engines for his friends, which enabled him to pay the fees for lectures on natural philosophy and chemistry at Edinburgh University. The lecturer asked Nasmyth to make demonstration apparatus for him.

He had by this time heard of Maudslay and determined to get a job in his works. To help he built a model steam engine and drew scale plans of it. Armed with these examples of his ability, he sailed for London in a Leith smack in 1829, and after an eight-day voyage he made his way to Maudslay's factory. The engineer was so impressed that he gave Nasmyth a job in his own private workshop to help him with his own prototypes at 10*s.* a week.

Maudslay thought the well-dressed boy had an allowance and wanted to serve as an unofficial apprentice. But Nasmyth had made a bargain with his father that he would earn enough money to keep himself or return to Edinburgh. The resourceful youngster managed to live comfortably on his 10*s.* He found lodgings at 3*s.* a week and then designed an oven which he had constructed by a tinsmith for 6*s.* He cooked for himself with this device, and his carefully kept housekeeping budget is an interesting picture of food prices in those days. His oven was simmering the food all day. The fuel cost 3*d.* per week. On three days a week he had a meat stew, consisting of ½ lb. to ¾ lb. of leg of beef at 3½*d.* per pound, with potatoes and onions to give bulk. On the other four days he had a rice pudding in the evening, and every day he had dry bread and coffee for breakfast. The total cost of this was below 4*s.* per week. When his wages were increased to 15*s.* after a year's employment, he augmented his diet with butter on the breakfast bread.

Maudslay died in 1831, and soon afterwards Nasmyth returned to Edinburgh to start making tools, so that he could start up in business on his own account. During this period he earned little beyond the fees for odd repairs or turning work brought by friends, but his family was comfortably off and his father, a keen mechanic, was as enthusiastic in making the tools as his son. In 1834 Nasmyth went to Manchester and took over an old mill in Dale Street as a workshop, and after two years was able to build his own shop at Patricroft.



31 A photograph taken in 1856 of Nasmyth standing alongside one of his steam hammers.

This was the Bridgewater Foundry, where he remained until his retirement in 1856, and where he invented the steam hammer.

Perhaps the description by a writer of the time that this tool was " one of the most perfect of artificial machines and noblest triumphs of mind over matter that modern English engineers have yet developed " was a little on the fulsome side ; nevertheless, it was an indispensable advancement in heavy engineering. The steam hammer was designed at the request of the builders of Brunel's *Great Britain* at Bristol. The shaft to drive the paddle wheels was far bigger than any forging previously undertaken, and invitations for tenders sent to every important foundry in the country brought refusals to undertake the work. Nasmyth was asked whether he considered the engineers could risk using a cast-iron shaft as no hammer existed to forge one. In reply he sent a sketch of a steam hammer in which the hammer head was driven upwards by steam, which then escaped and allowed the hammer to fall by gravity. Although the idea was seen to be practicable, it was never adopted because the *Great Britain's* design was changed to use screw propulsion. The hammer was offered to some of the firms who had been unable to make a large forging, but they all replied that there was normally no call for such work and therefore no need for the hammer.

Then M. Schneider, head of the Creusot works of France, called at the Patricroft factory while Nasmyth was away, and was shown the design of the hammer among various other examples of the firm's work. The event was regarded as of no importance and Nasmyth was never informed that Creusot had seen it. Years later, in 1840, Nasmyth visited France himself and paid a call on Schneider, who conducted him round the works. Nasmyth saw some very large forgings and enquired how they had been made. "But with your hammer, m'sieu ! " he was told by Schneider. Thus Nasmyth found himself in the unusual position of an inventor who did not know his device had been made and was in use.

On his return, Nasmyth tried to persuade his partner to advance the money for patenting the steam hammer. This was the period of the " hungry forties " and business was bad. There was not the necessary money for such matters. Nasmyth's brother-in-law came to the rescue and the patent was secured in June 1840. Soon afterwards a 30-cwt. steam hammer was working in the Patricroft shops, and the news spread around the engineering works of the North and Midlands, with the result that within a year or so its use became general. It is doubtful whether the great advances made in iron hulls for ships at this period would have been economic or even possible without the Nasmyth hammer, and certainly the production of large marine engines and more particularly heavy calibre guns would have been prohibitively costly.

Machine tools have developed remarkably since these pioneers showed the way to overcome the shortage of skilled labour. Special-purpose tools which carry out numerous processes simultaneously, such as automatic lathes and multiple drills, are to be found in every workshop. When Mr. Churchill called to America, " Give us the tools and we will finish the job," in the Second World War, the literal meaning was as important as the symbolic one. The machine tools which came across the Atlantic were as important as the tanks and aircraft, for they enabled our industrial potential to outclass the enemy. Similarly, in the post-war production drive it was the machine tool which enabled the change-over from war to peace manufactures to take place. That war-to-peace change also brought hitherto unknown problems to the machine-tool maker. Absolute precision of action he had mastered. Now, with the emergence of new industries in the chemical field and the universal shortage of man-power, he needed machine tools which could smell, see, and count. He invented them. A tooth-paste manufacturer now has a machine which will tell him whether the aroma of his product is exactly the same each month with far more exactitude than the human nose. The electronic eye operates hands which sort products by colour and size with lightning rapidity ; typical users are pea-canners, who want to reject shrivelled, yellow peas, and confectionery manufacturers.

Last of all, the robot-like machine tool came into its own in the research on atomic energy. Machines took over the mathematical problems and solved equations in a few seconds where a man would have been busy for weeks, and in the atomic stations themselves the primary idea of the machine tool as a mechanical hand reached its zenith of perfection. Rods, remarkably like human fingers, had to be made to grope and grip in conditions lethal to human beings. It is thought-provoking to realise that without these mechanical hands the staggering triumph of putting the theory of nuclear fission into practice could not have occurred, for the experimenters must have died. The comparatively humble little servant of industry, the machine tool, is therefore the rightful means of introduction to the zenith of modern industrial success—the harnessing of the power of the atom.

8

POWER OF THE SUN

THE TRIUMPH OF NUCLEAR FISSION

THROUGH a grey stone arch in Cambridge lies the laboratory which has unlocked a secret of the universe. The building in Free School Lane of the old university town is the place where man first learned to split the atom and so release the fundamental power of Nature. Here, more than in the vast plants which were part of the bill of £500 millions which America spent in order to produce the atom bombs that flashed destruction on Hiroshima and Nagasaki in 1945, is the birthplace of atomic power.

It is a tragedy of the modern world in which we live that this supreme gift of science to industry should first and foremost strike fear into the minds of humanity. But the scientists are not to blame for that. Science is the servant of all. Its purpose is the pursuit of knowledge and the application of what it finds. Like the symbolic crocodile which is carved on the walls of one of the rooms in the Cavendish Laboratory, science never looks back. Inevitably, the force of the universe would be revealed and harnessed. It is well that the discovery came to Britain and her friends when it did, for therein lies hope of good.

But exaggeration about the stupendous gifts which atomic power has already promised to industry should be avoided. Undoubtedly its greatest power is the power for evil—for the next war, which Professor Harold Urey forecast would be " fought with atomic bombs, and the one after it with spears " —and its power for good is not so spectacular nor revolutionary. Press reports have dramatised the bomb beyond all sense and reason, unless one feels that they are true because of the ability of the atom to release its power suddenly. As a source of industrial fuel and power, it has been calculated that, in replacing coal and oil, it would not alter the amount of work which mankind had to perform by more than ten minutes or so in the working day, so that a leisurely atomic paradise is not round the corner. Further, the energy released by each atomic bomb used on Japan was equal to that produceable by about 2,500 tons of coal—sufficient to keep Britain's life going for about five minutes.

Only the first few sentences of the story of the harnessing of atomic power have so far been written. But the preliminary work which made a philosopher's dream a practical possibility can be traced back to the days of Cavendish, after whom the Cambridge research centre is so rightly named. When Cavendish read his paper on " Experiments with Air " to the members of the Royal Society on 15 January, 1784, he marked a famous date in history. The great globe in which he demonstrated that water was made of two gases is preserved by Manchester University. This device started man on a road of discovery of the ways to take elements to pieces and to put them together again.

The man who was to put forward the atomic theory was eighteen at the time of Cavendish's water experiments. His name was John Dalton, the son of a Quaker weaver in the village of Cockermouth, Cumberland, not very far—appropriately enough—from the new atomic factory at Sellafield. His parents were poor, and though they did their best, Dalton had to leave school at the age of eleven. In that time he had amassed more knowledge than his fellow pupils, with the result that he returned to the school a year later as a teacher—a profession not without danger, for many of the boys in his class were older than he was, and frequently the burlier scholars challenged the master to a fight when the bell rang. At fifteen he became a teacher at a boarding school at Kendal. He taught himself as well as the boys, and by the time he was nineteen he had a good knowledge of Latin, Greek, French, and mathematics.

He remained at the school for some ten years, and in 1793 went to Manchester as tutor in mathematics and natural philosophy at New College. Manchester remained his home for the remainder of his life, but his growing reputation took him to lecturing at London, Edinburgh, Glasgow, Birmingham and Leeds. With the simple habits of his creed, Dalton was quite unchanged by his international reputation as a theorist, mathematician, and chemist. Scientists who came to visit him would have to wait patiently while he took some small boy through the rudiments of arithmetic, and often he was missing altogether, wandering in the countryside. These walks he took for a purpose, for he made weather observations every day of his life, amassing some 200,000 precise observations in neat little notebooks which gave details of temperature, humidity, and so on. It was this study of the air which set him thinking about the constitution of the atmosphere, and wondering how a mixture of two or more gases should constitute an apparently homogeneous mass.

His atomic theory was published in 1808. He used symbols for each element—a diamond for oxygen, a dot for nitrogen, and so on. He showed that chemical elements are composed of minute particles of matter which remain undivided in all chemical changes ; each type of atom had a different weight ; different elements had atoms differing in weight, and the chemical combinations were caused by the union of atoms in numerical ratios.

Such a revolutionary concept naturally took time for acceptance. Gradually the world's physicists came to see that Dalton had put his finger on the mystery of matter. They began to shower honours on him. He remained quite unchanged, a simple, charming, and gentle man who found all the rewards he needed in the discovery of truth. In 1833, when he was sixty-seven, he was granted a small State pension, and he died from a stroke in 1844. The people of Manchester instituted the Dalton Scholarships at Owens College in his memory.

Now, nearly a century later, the same type of memorial is being arranged by the Royal Society for Lord Rutherford, the founder of the Atomic Age, who died in 1937. Ernest Rutherford had some characteristics remarkably like those of Dalton.

He had little regard for money, and he left only £7,500, part of which was a legacy from his father. His research work at Cambridge was carried out on a " string and sealing wax " basis, and he never badgered anyone for money. There is a story told by an American scientist who was taken round the Laboratory and saw a man turning a bicycle crank connected to a dynamo. " I think we can get the money for an electric motor," said Rutherford as he passed. Then, to his visitor, he added : " You know who that was ? Aston, the Nobel Prizewinner." For a moment the American intended to take £10 from his wallet and buy the laboratory a motor. Then he thought better of it. " No ; that would spoil it. That's a spirit money can't buy," he muttered to himself.

32 John Dalton, the gentle genius who propounded the atomic theory of the construction of matter in 1808.

Rutherford was born in New Zealand of a Scottish father and a school-teacher mother in 1871, both of them with a strong Calvinist outlook. Young Rutherford spent his childhood in the open air, and throughout his long life he never lost this appearance of being an outdoor man. With shaggy moustache and ruffled hair, an excitable, zestful manner of conversation, and a massive frame, he was the antithesis of the typical student or scientist in appearance. His charming, gentle personality (except with people who had specious arguments) was the mainspring of the group of scientists of many nations who talked with him, came to work with him, and developed the ideas which flowed from his fertile brain in experiment after experiment.

As far back as 1903 he jocularly stated that " some fool in a laboratory might blow up the world unawares", for by that time he was well on the way to splitting the atom. If he had not died at the age of sixty-six in 1937, with faculties and physical energies quite unimpaired, atomic fission might have been effected some years earlier than it actually was, even with the accelerated effort that was undertaken in the war.

As it is, every name connected with atomic science is that of a pupil of Rutherford's who was either directly under his aegis in the Cavendish Laboratory or has followed in his pioneering footsteps.

When Rutherford arrived in England the Cavendish Laboratory was already a Mecca for world science—and the pilgrim from New Zealand had to borrow the fare to get there. Opened in 1874 as a memorial to the great scientist, Henry Cavendish, the Laboratory's first chief was James Clerk Maxwell, and he was followed by Lord Rayleigh. In turn came Joseph John Thomson, one of the great teachers of modern physics. It was Thomson who first determined the speed of the particles in the beam of a cathode ray. He saw that these particles must be lighter than charged atoms of matter. In Rutherford's early days at the laboratory the great feature of interest was this radio activity, discovered by the Frenchman Becquerel in 1896. In conjunction with Professor F. Soddy, Rutherford gave a scientific explanation of the phenomenon in 1902, in which he stated that the atoms (so named from a Greek word meaning uncuttable because they were regarded as the very basis of all matter)

33 Dalton's painstaking observations of natural phenomena occupied his life. This picture shows him collecting marsh gas for his study of the atmosphere.

were exploding, and that uranium was producing helium—one substance was in fact producing another which was not there before. The three rays emitted by the radio-active substance being studied, named alpha (the atoms of helium), beta (electrons) and gamma (electromagnetic) waves, enabled Rutherford to study what was happening to the original atom. For nine years he worked on the subject, proving that the atom was not the seed of matter, but itself a complex structure with electrons circulating round a nucleus just like the planets round the sun. Different pieces of the jigsaw puzzle of matter were now fitting together. In 1905, Einstein, in his famous relativity theory on the speed of light had shown that space and time, matter and energy were interchangeable pairs. If, therefore, mass could be destroyed it would become energy —an incredible amount of it.

To release the energy by battering at the fortress of the atom became Rutherford's dream. Even though Government work during the First World War interfered with his investigations, he did not allow these duties to stop it altogether—a fact which annoyed some of the big-wigs of the Government. When he gently explained to one of them that he believed he was about to prove his ability to smash the atom to order and this was far more important than the war, the effect may well be imagined. This work was undertaken at Manchester, but in 1919, when Thomson died after thirty-five years' work at the Cavendish, he was appointed Director of the Laboratory. His team included men whose names are now world-famous : Sir John Chadwick, Professor P. M. Blackett, Professor M. L. Oliphant, Professor (now Sir) John Cockroft, Professor J. D. Bernal, and Dr. F. W. Aston.

Chadwick was Rutherford's principal colleague in the experiments of the early nineteen-twenties. He had been studying in Berlin in 1914, and was interned for the duration of hostilities. On his return one of the first problems Rutherford expounded to him was the identification of a particle which he believed to exist in the atom which was neutral in contrast to the positive charge of the nucleus and the negative of the electrons. German physicists and the French scientist

Frederic Joliot were experimenting in this field, but it was Chadwick who proved that there was indeed a third particle —the neutron.

The dream of 1903 was slowly coming true. In 1932, one of the most important dates in British scientific history, the Cavendish was changing one element into another (the work of John Cockroft, a young Manchester electrical engineer, and Walton, an Irishman), proving the existence of the neutron, and building an " atom gun ".

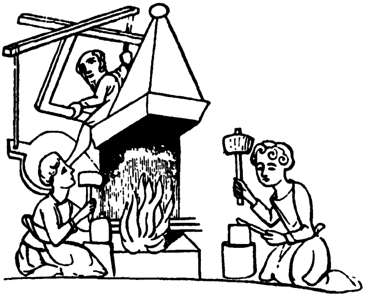
The last invention came as a result of Rutherford's characteristic description of his hope that his assistants could " produce a million volts in a soap box ". They didn't quite achieve this, but a machine to apply several hundred thousand volts to accelerate atomic particles was duly built and used. In 1932 nuclei of hydrogen atoms were being stimulated by electricity to release much more than their own quantity of energy, and Cockroft and Walton were disintegrating lithium with them. Important as this work was, it was no more than a step forward, because it was about a million to one that any one hydrogen nucleus had enough energy to do its work on the atom, with the result that the explosion did not spread. The answer to this difficulty came from California where Professor E. O. Lawrence devised the cyclotron, a drum-like machine converting a few hundred volts to the equivalent in accelerating power of millions. With a beam of this energy, nuclei could be torn asunder.

The whole scientific world was by 1934 busily engaged in the new study. From Germany, fleeing from racial persecution, came Jewish scientists to the haven of England, the latest of a long line of brilliant men who have richly rewarded this country for her succour, by the gifts of their inventive genius. Others, like Fermi of Italy and Halban of Austria, found safety and scope for work in America and France.

Before he died, Rutherford saw free men everywhere working in co-operation and mutual respect to use the treasure-house of power behind the door that he had unlocked. He must also have realised that ponderously but remorselessly the world was drifting to war. At that time it did not seem likely that nuclear fission would offer any greater source of explosive energy than that provided by chemical methods. Even if his brilliant brain may have envisaged the speed with which discoveries could be made under the impetus of war, he knew that Britain had incomparably the most formidable collection of experts and the best knowledge of any nation on earth. About the time of Rutherford's death, many of the experts on atomic physics temporarily transferred to the development of radar, but we maintained our lead until 1941. In the summer of that year, American scientists began close liaison with their British colleagues, and though a project was launched in September to construct an atomic bomb solely with British resources, the more sensible plan of leaving the practical side to the New World, while Britain did what her severely strained scientific man-power could achieve on the theoretical side, was put into operation. Our heritage of atomic knowledge was unreservedly handed over to help the common achievement. By 1943 the United States was the leading authority on nuclear fission, and seventy-five British scientists were helping in the race which finished when a dazzling flash and a mushroom of smoke appeared over the Los Alamos Desert in New Mexico. As the roar died away, man knew that he had discovered the method of releasing the power by which the very sun itself gave life to the system of planets spinning around it.

II

MANUFACTURE



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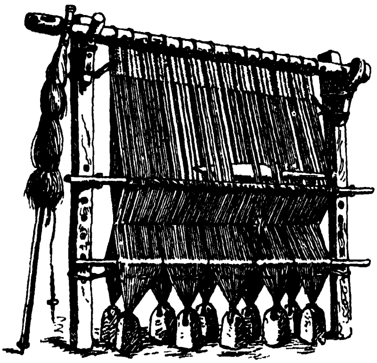
34 Spinning as a home industry of the womenfolk in medieval times.



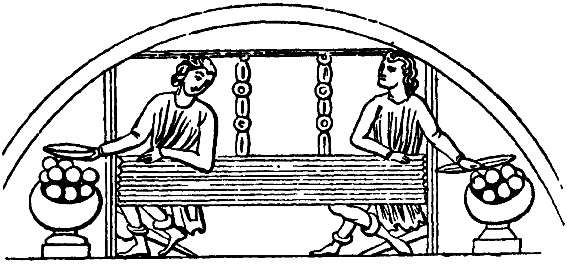
35 A hand loom, still in use to-day in the same form as it was in the Iron Age of prehistory.

9

WARP AND WEFT

A THOUSAND YEARS OF TEXTILES

THE 850,000 people who can earn their living in Britain in the textile industry are the descendants of the earliest pioneers of any important manufacture in these islands. The people of overseas countries who buy our woollen and worsted cloth because it is the best are the customers whose ancestors had just as high a regard for it eight centuries ago. Truly Britain was then the land of the golden fleece. Incalculable wealth came from our processed wool, and the trading in it was the motive power behind our explorers, sailors, and soldiers. There is a widespread tendency to ascribe political, religious, or dynastic factors to almost every war of the past in which England was engaged. More often trade was the underlying cause, and until very recent times trade meant one thing only, wool. Up to the time of the Machine Age, it is necessary only to study the woollen industry to obtain a complete picture of our economic history. The earliest craftsmen's guilds were those of the weavers. They were a privileged class, the darlings of the King and Government. Organised in the reign of King John, the weavers were given a charter by Henry II, and even then the industry was ancient. King Alfred's mother was a skilful weaver, and Offa, King of Mercia, agreed to send Charles the Great cloaks of the same pattern as used to be sent " in olden times ". Every device was used to maintain our supremacy. As early as 1271 foreign weavers were being invited to come to work in England, with no taxes to pay for the first five years, and some years earlier the export of raw wool was forbidden. Best of all, these early weavers realised that quality was the most certain means of achieving supremacy.



36 Weavers portrayed in a section of a medieval stained glass window.

The ancient guilds set a very high standard for their members. " Made in England " was a hall-mark of quality certainly as early as the thirteenth century. Standards of work were drawn up by men who, even if they became wealthy in their business, were undoubtedly impelled by lofty principles on right and wrong. Shoddy goods, scamped and defective work, shady dealings, or exorbitant profit could be punished by expulsion from the guild, which meant not only social disgrace, but the complete cessation of a means of livelihood. By the sixteenth century these self-imposed controls had created officials known as " searchers ", picturesquely dressed in the regalia and costume of their company, who visited all the great mediæval trading fairs as well as the London warehouses to measure or weigh samples of goods which came under their jurisdiction. Defaulters could be summoned to a Court of Record, at which the Master and Wardens of the Company could not only fine the delinquent, but imprison him as well. The civic authorities permitted this because the honour of the trading city of London as well as the reputation of the craft were at stake.

How severe were the punishments for shoddy work is shown in the case of a wealthy cloth merchant named Roger Chowne, who was found dealing in a flimsy cloth got up to look like English broadcloth one day at his premises in the Chepe (Cheapside). The Lord Mayor of London at the time was himself a clothworker, Sir Rowland Haywood, and the case came before him. The terrified man tried to bribe his way out with a donation of 1,000 crowns. It was a large sum of money, but admittedly a reasonable investment to avoid what in the event occurred. Not only did Chowne find his business in ruins and himself in permanent disgrace, but one of his ears was cut off, and he was pinned to the doorway of his warehouse by the other.

Such care of the industry's reputation was not confined to London. Every cloth town adopted similarly stringent measures. Coventry, a great mediæval cloth market, had a Searchers' House where every inch of cloth made locally was examined. Four workmen examined the material and six more watched them to see that they missed nothing. In Norwich much the same procedure was employed. Once passed, the cloth was marked with the city seal.

The guild system of textile production, in which master, journeyman, wage-earner, and apprentice worked together, lasted from the twelfth to the sixteenth century. It gave way to the domestic system which flourished particularly in the North and the West Country. The pivot was the clothier, a capitalist who rarely made cloth himself. He was a trader, buying his cloth from cottages and farms, and sometimes financing the suppliers during lean times. A typical clothier of the sixteenth century was Peter Blundell, born at Tiverton, Devon, in 1520, of very poor parents. He built up a business which enabled him to leave a fortune equivalent to £250,000 in modern currency. Tiverton's famous Grammar School was founded by a legacy in Blundell's will.

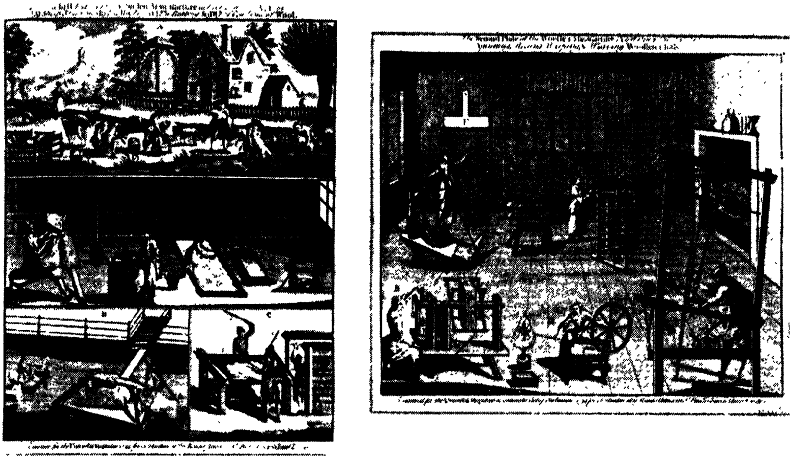
Some of these Tudor clothiers brought the cottagers under one roof and turned them into a wage-earning industrial class. Such factories (sometimes in monasteries sold to the owners by Henry VIII) were to be found in Newbury, Oxford, Malmesbury, Abingdon, Lavenham, and Cirencester, among other places.

It is surprising to find how large some of these mediæval mills were. At Newbury, for example, John Winchcombe had a flourishing factory before Elizabeth came to the throne. He was centuries before his time in his division of labour and centralisation of production, and his works must have been the largest of any kind in Britain, or even the world, at that period. It was a "sheep's back to finished cloth" establishment. Fifty men were employed to shear the sheep, an unknown number of children then sorted the wool, and 100 women carded it. Two hundred girls spun the yarn, and 400 men and boys were engaged in weaving it. Twenty fullers, forty dyers, and eighty technicians to raise the nap completed the processing.

This mediæval factory system was destroyed by legislation (notably in the Weavers Act of 1555) because of the dangers of conspiracy. Until the arrival of steam power, the cottage system returned as the mainstay of the textile industry, with the difference that the weaver did not normally provide his own raw material. He owned the loom (it cost about £4 unless he built one himself). By the latter part of the eighteenth century he could earn an average of 10*s.* a week on a piece-rate basis. Oat bread, his staple food, cost 1*d.* for a 10-oz. loaf, cheese was 4*d.* per lb., and butter 6*d.* per lb. Although there were times when there was no work, the weaver was better off than the agricultural labourer, particularly if his wife and children could help. But weaving had to go on for fourteen hours a day in winter and seventeen in summer in order to earn that 10*s.* weekly average. In winter this was an impossible routine for many weavers : they could not afford the illumination needed after nightfall.

Another material was seriously challenging the supremacy of wool by the end of the seventeenth century—" King Cotton". This material was something of an innovation for a race which had from time immemorial worn wool, linen, or leather. Its arrival is said to have occurred when cotton workers fled from Antwerp after its capture by the Spaniards in 1585. England, as usual, provided refuge and promptly investigated the commercial possibilities of their guests' skill. Calico was arriving from India within a few years of this development, and there were supplies of raw cotton available from the Near East and brought back by the Merchant Adventurers.

The new English industry was located in the Manchester area. The usual reason given is that moist atmosphere keeps the threads supple, but a more potent reason was probably



7 Two eighteenth century prints showing every stage of woollen manufacture from sheep shearing to the finished cloth.

that the area was free from the guild and craft restrictions imposed in London and other ancient centres.

The East India Company brought a steadily increasing amount of cottons from India, and by 1700 the woollen interests agitated violently against the trade. The Government found a compromise by forbidding the use and wear of imported printed or painted calicoes, with the result that plain materials were imported and then printed in this country. Efficient work resulted in these cottons being cheaper than ever, and once again the woollen industry protested. In 1721 it managed to persuade Parliament virtually to veto all cotton material imports. Promptly the cotton spinners of Manchester and the Clyde Valley increased production, and in the event the competition became worse than before. In 1760 imports of raw cotton were 8,000 tons. Forty years later, when the machine looms were in operation, they rose to 25,000 tons. The majority of the inventions to be described were for the benefit of the cotton industry, though, of course, some could be adapted for the woollen and worsted trades, but under the stimulus of mechanisation cotton had won a spectacular victory over wool by 1800. Machinery powered by steam in factories built close to the coal-mines put cotton in the forefront of the Industrial Revolution.

Workmen, their habits still based on the cottage industry system, where the whole family shared in the work, took wives and children to the new factories. Soon the owners saw that children alone could do the work if driven and even lashed by the overseers. Large numbers of pauper children were shipped like slaves into the factories from the age of seven upwards, and made to work fourteen or fifteen hours a day for six days a week. The wages were as low as 3*s.* 7½*d.* a week.

Such unhappy results were due to the rapacity of the employers and the greed of workmen who readily took their children into the mills. They were certainly not the responsibility of the inventors who made such industrialisation possible. With a few exceptions, the men who invented machines for the textile industry derived little profit from their work, and most of them were actuated by the desire to lighten tedious labour.

The brief survey of the early stages of the textile industry has been made so that the reader may appreciate how long a period of time is covered by inventions for the processing of wool and cotton into fabric. Devices which improved quality or accelerated output appeared long before the Industrial Revolution. The spinning wheel, replacing the distaff, is believed to have been introduced from Italy in the fourteenth century. Its effect was to widen the bottleneck of production, for a weaver with one loom could use yarn faster than a dozen distaff spinners could produce it.

An unknown man invented the fulling mill, by which the laborious process of thickening and felting wool fabric by trampling it in water with the feet was replaced by a mill pounding it with water-operated hammers. Some of the earliest workers' riots were caused by these mills, which resulted in their being banned in the thirteenth century.

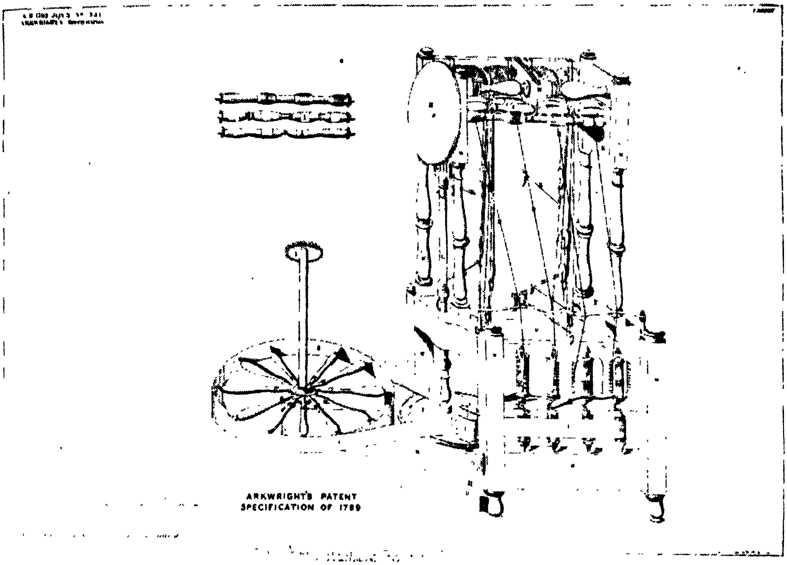
The first outstanding invention for weaving since pre-Christian times was the fly shuttle, patented in 1733 by John Kay. The son of a wealthy clothier, Kay was born at Walmersley, Lancashire, in 1704 and was educated in Europe.

38 Cotton manufacture in 1833: female labour engaged in carding, drawing and roving.

Put in charge of his father's textile factory at Colchester, Kay worked on a device to cast the shuttle across the warp mechanically, so that one man could operate a loom instead of two, with the result that each weaver earned more money with less energy. Such was the actual result, but the Colchester weavers did not see the advantages. They refused to use the fly shuttle and they drove Kay out of the factory. He went to Leeds, where the West Riding clothiers adopted his shuttle, but paid nothing in the way of royalties. A series of ruinous lawsuits gave Kay a technical victory, but no damages. He then went to Bury, the town near which he was born, and lived for some time in retirement. But the itch to invent was still there, and he dabbled in improving spinning wheels. Local workpeople heard about his work, attacked his house and attempted to kill him. He escaped, wrapped in a roll of cloth. He went to live in France and died there in obscurity, his last resting place unknown. The supreme tragedy of all is that Kay wrote to a friend saying: "I have a great many more inventions than I have given in, and the reason I have not put them forward is the bad treatment I have had." The loss to industry epitomised in those words can only be conjectured.

Mechanical improvements were coming, whatever a suspicious and reactionary working population might do. Five years after Kay's shuttle appeared, Lewis Paul took out a patent for a roller spinning machine. A series of rollers drew out the raw wool or cotton by a variation in speed between one set of rollers and the next. Little is known of Paul except that he was the son of a French refugee and was a friend of Dr. Johnson. Paul was helped, financially and practically, by a mechanic named John Wyatt, and after the machine had been shown in operation, the Editor of the *Gentleman's Magazine* furnished money to erect a mill at Northampton, while Paul and Wyatt scraped together sufficient to erect another at Birmingham. The factories soon failed through lack of capital and on account of faults in the spinning machine, and nothing more was heard of either inventor, their lot doubtless being oblivion in a debtors' prison.

The Paul machine is one clue in the mystery about Richard Arkwright. Whether he stole Paul's patent, whether that formality had been allowed to lapse, or whether an assistant stole the idea are questions that cannot now be answered. What is certain is that Arkwright produced the first successful automatic spinning machine, aided by a clockmaker named Kay, who, so far as it is known, was no relation of the inventor of the fly shuttle. Arkwright was born at Preston in 1732, the youngest of thirteen children. While still a small boy, he went to work at a barber's in Bolton, and he must often have heard his master's customers moaning about the inevitable trade topic—the shortage of yarn for the weavers. He saw that fortune awaited the man who could solve this problem, and though he was no mechanic his head teemed with ideas. These were turned into models by Kay the clockmaker. Barbering and family were neglected, savings spent, and still perfection eluded him.



39 Diagram included in Arkwright's specification of 1769 for his automatic spinning machine.

Friends fed and housed him, and eventually the first machine was set up in the house of the Headmaster of Preston Grammar School.

The temper of the local workers was well known, and for safety's sake Arkwright went to Nottingham, where two manufacturers named Strutt and Need financed further experiments. The machine was patented in 1769, but a further five years and a total of £12,000 were spent before any profit was yielded. The trouble came not only from the workers (they destroyed the Arkwright mill at Chorley in 1779) but from the hostility and dishonesty of the factory owners. Some simply refused to buy his yarn, though it was of far better quality than that from the cottage spinners; others merely copied his machines and spun their own yarns. When Arkwright took legal action against them, they dug up data on other devices and showed that his patent was irregular in any case, and it was cancelled. Disgusted and disheartened, Arkwright for a time toyed with the idea of making Lanark the " Manchester of Scotland " by helping with the erection of the most modern spinning mills in the world across the Border, and he certainly had interests in some mills in the Clyde Valley. In a few years Arkwright became one of the wealthiest business men of his time, a forerunner of the self-made industrial magnates whom the Industrial Revolution was to produce so often. Made a partner in many concerns, he worked from five in the morning till nine at night, even when he was more than fifty years old, and at this period of his life he also decided to remedy the defects of his education by cutting out two hours of sleep to improve his grammar and writing. He always travelled with four horses so that he could keep up the maximum speed.

James Hargreaves, a weaver of Standhill, near Blackburn, was the next great textile machinery inventor. He made a device on which several threads were spun simultaneously, and because it performed the work usually done by his wife, he called it his spinning jenny. At first eight, and later as many as 120, spindles could be handled by one spinner, and Hargreaves realised all too well what the workpeople of the town would think of his device. For a time he used it secretly in his own home, producing the weft for his own loom. But the machine made a noise, and the neighbours got to know. He was also compelled to sell a few machines to buy food for his family. In 1768 a mob burst in and smashed the machine to pieces. Like Kay, Hargreaves took his family to Nottingham, where he patented his machine, scraped enough money to start a small factory, and before he died in 1778 was in fairly comfortable circumstances.

One of the spinners who used the jenny was Samuel Crompton. He lived at Firwood, near Bolton, and was sixteen years old at the time when the mob wrecked Hargreaves' home. Crompton lived in a semi-derelict house with his mother. Well educated, but with no mechanical training, the youth had that spark of imagination which made him stand out from his colleagues bent only on smashing any machine invented to lighten their work. Crompton worked on improvements to the jenny in secret, using a few tools he

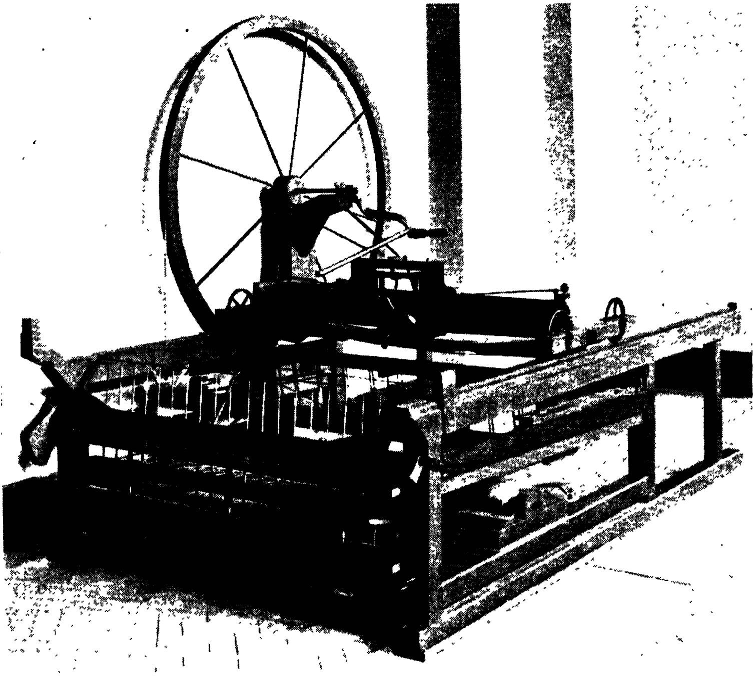
40 A new feature in late eighteenth century England : Arkwright's cotton mill at Cromford blazes with light as work goes on by night.

could buy out of his wages. During outbursts of wrecking which took place in the district, he used to dismantle his machine and hide it in the rafters of the roof. When his mule which combined the principle of the jenny and the Arkwright spinning machine, was perfected, he used it to make yarn for himself. The superior quality aroused the suspicions of other workers, and they came around to see what he was doing. He erected a screen to prevent them seeing his machine, but eventually he succumbed to the blandishments of the Bolton townspeople, who promised him a generous reward for his secret. Manufacturers were supposed to subscribe up to a guinea ; a good many refused to do so, and the total collected came to £106, indicating that more than a hundred firms had obtained details of a device which Crompton was too diffident to patent. The experience soured the character of this shy introvert. He could have acquired wealth as Arkwright did ; instead, he remained in the background, waiting to see if someone would redress the wrong done to him. Thirty years later, when five million of his mules were in use, Parliament was pressed to confer a reward on the inventor. Crompton went to Westminster and overheard the principal supporter of his claim, Spencer Perceval, Chancellor of the Exchequer, reveal that the sum he proposed was £20,000. A few minutes later Perceval was assassinated by a lunatic, and the nation's legislators, who in the same session granted £50,000 to purchase property for the heirs of Wellington, considered £5,000 would cover Crompton's case. Such was the total reward of the man by whose invention a quarter of a million spinners and weavers were earning their living when he died in 1827.

The story of Edmund Cartwright's career is almost as depressing. Born in 1743 in Nottinghamshire, he was educated at Wakefield and Oxford, taking Holy Orders at the instigation of his parents, despite his own desire to enter the Navy. An intellectual, gentle man, he rusticated in the peace and obscurity of livings in Cheshire and Leicestershire, where he might well have lived and died without a note in our history books if he had not taken a summer holiday at Matlock in 1784. There he met some Manchester millowners who were deploring the situation in which spinning methods outstripped weaving.

The quiet little clergyman smilingly suggested, "Then Mr. Arkwright must set his wits to work to invent a weaving machine." This, he was told by the experts, was impracticable.

With all the optimism of the amateur and the ignorance of a man who had never seen a working loom in his life, Cartwright got a carpenter to build him a loom in the vicarage to his own design. Whether it was like the Biblical looms of which he had most knowledge cannot be said, but it was an unwieldy contraption. The Reverend Cartwright was,



41 Replica of Hargreaves' spinning jenny, the machine which enabled 8–120 spindles to be handled by one worker.

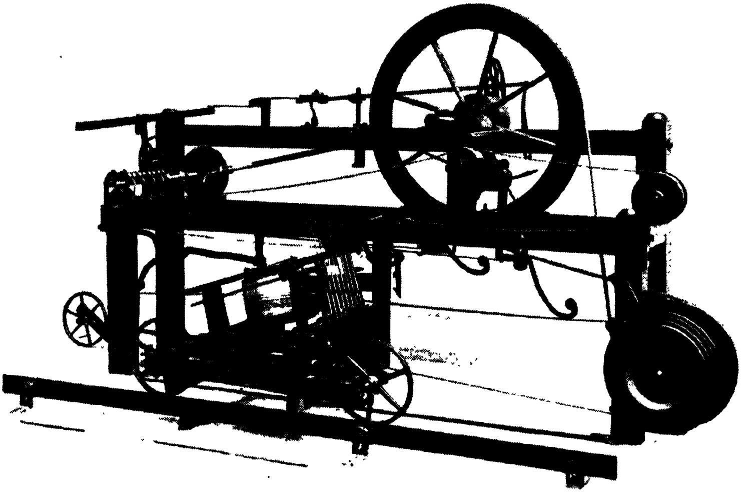
however, delighted and promptly patented it. When he decided to see the looms used in the North he was amazed at their ease of operation. He copied one and then in the next eighteen months (till 1787) worked on adapting it for power operation. At a factory he acquired at Doncaster the loom was first operated, driven by the perambulations of a bull, and later by a steam engine. Then in 1791, a Manchester concern installed a few looms as an experiment, with accommodation for a total of 500 if the first proved successful. The employers found the weavers' output was doubled. Instead of sharing the benefit by increasing wages or decreasing hours of work they simply halved the payment. For once the weavers' anger is very understandable. They burned the mill.

Cartwright found that no other millowner would risk such a disaster, and he had also to close his own plant at Doncaster. Although his calling would have permitted him to gain a livelihood in the peace of some rural parish, the urge to invent could not be so easily shaken off. He removed himself to London, where he devoted himself to invention. One device was a combing machine (to prepare the raw wool for spinning), which was not, however, successful. This intricate device occupied the attention of inventors for many years after Cartwright's attempt. Donisthorpe and Lister (inventors of the Nip machine in 1851), Isaac Holden (who designed the Square Motion machine), and James Noble (whose machine bears his name) were the engineers who achieved the goal.

In 1801, at the age of fifty-eight, Cartwright petitioned the Government for recognition of his patent rights, and in his evidence stated that his inventions had incurred him in losses of £30,000. A tardy recognition was given with a grant of £10,000 by the Exchequer, and Cartwright retired to a farm in Kent, where he lived quietly and happily until his death in 1823.

The wealth of invention brought revolution to Britain—quite as profound if not so dramatic or bloody as the holocaust which had swept France a few years previously. The gentle Cartwright, the pot-bellied, swashbuckling Arkwright, the shy Crompton, and the homely Hargreaves could not have envisaged the powers that they were unleashing. Nor did Parliament show either the desire or ability to control them. The Government had a war on its hands. Ruthless exploitation by employers, appalling working conditions, and bitter rivalry were allowed to run riot. The traditional hatred and suspicion of the workpeople for anything which looked as if it would save man-power rose to a peak in the first decade of the nineteenth century, and the workers in textiles, the first affected by machinery, led the battle for their rights, stimulated by hunger which resulted from poor wages, bad harvests, and a national economy strained to the limit by war.

In 1811 Lancashire, centre of the new machine mills, was a sorry place indeed. One-fifth of the urban population was



42 A model of the mule, in which Crompton combined the inventions of Arkwright and Hargreaves in one device.

in need of charitable relief, and those in work found that wages had declined from 15 to 33 per cent. This meant a wage of between 9*s.* and 15*s.* a week at a time when the quartern loaf cost 1*s.* 2*d.* The working population, still with a vivid memory of the countryside, was crammed into towns which grew week by week, though they were still small by modern standard. Manchester and Liverpool, for example, were by far the largest towns except for London, and they each had a population of about 100,000. Towns like Bolton, Huddersfield, and Stockport had 15,000, and to gain a picture of the uneasy birth of steam power in the looms of the North the story of Stockport is a typical example to take. Like many another group of cotton workers, the mill people of Stockport applied to the magistrates for help and were told to petition Parliament for succour. A deputation saw the Home Secretary and returned with the message of cold comfort : " Have patience."

The condition of the workless may be imagined. But those who could get work were little better off. A Stockport cotton weaver in full work could earn 9*s.* a week at sixteen hours a day for six days a week. The mainstay of his family's diet was potatoes, and even these had trebled in price to 1*d.* per lb.

These figures refer to workers on the hand- or water-operated looms. The price for weaving twenty-four squares of cambric in Stockport fell from 25*s.* in 1802 to 10*s.* in 1811. This fall was partly due to depression, but mainly to the steam looms installed in two Stockport factories in 1806. By 1813 the number had risen to fourteen between Manchester and Stockport, driving some 2,400 looms.

During the winter of 1811–12 the troubles came to a head. The Luddites were abroad in the land, smashing machinery which they believed to be the chief cause of their unemployment. Named after an apprentice who smashed his stocking frame at Leicester, and spreading into the hosiery trade of Nottingham, the outbreaks of Luddism shocked the country into action—unfortunately of suppression. Some 12,000 troops were employed in combatting the outbreaks, and though at the time there were many who were convinced that the nation was on the verge of revolution, the facts seem to be that the Luddite anti-machine outbreaks were small, only locally organised, and remarkably controlled, for looting was exceptional and the workers rigidly restricted themselves to smashing the hated machines.

In February 1812 the Clerk of the Stockport magistrates reported that the weavers, " stirred up by a few desperate characters from Ireland, do meditate the destruction of the Looms worked by steam ". The magistrates asked for cavalry and enrolled special constables. In March the first attack came, when a crowd attempted to fire a factory one night. A month later, on a Sunday morning, a crowd headed by two men dressed in women's clothes and known as " General Ludd's wives ", stoned the house of a steam-loom-owner named Grodair at Edgeley. There were some 3,000 rioters, and they visited factory after factory, finally returning to Grodair's estate and burning down a cottage. Forced subscriptions were collected during the following nights and then the Luddites moved to the Oldham district, where there was a large steam loom mill owned by a Mr. Burton. In the expectation of an attack, the mill was protected by guards, and five men were killed and eighteen wounded in the ensuing battle. The Luddites returned the following day and completely destroyed the mill. By this time the Stockport riots were merely part of the pattern which spread from Carlisle to Truro. Such outbreaks continued on a minor scale for many years, obtaining a political flavour as time went on, and not so directly concerned with machines. The birth throes of the Industrial Revolution were over. Textiles flourished as never before—maybe the real memorial to the inventors who made it possible. They were certainly little honoured in any other manner.

With these comparatively simple little machines designed to replace tedious and inexact manipulations by human beings the Machine Age had arrived. Some of these machines were, of course, of wood. But as they grew bigger and worked faster the worker in metals had to be called in to produce strength in his pieces such as man had never needed before. Fortunately for him, Britain could provide him with plenty of the materials he needed—ores to purify and fuel with which to do it. The smith was among our most ancient craftsmen. He was not slow to meet the new demands the inventors put before him, and, as we shall see, the Machine Age was also the Iron Age.

43 A model of a weaver's hut in Saxon England.

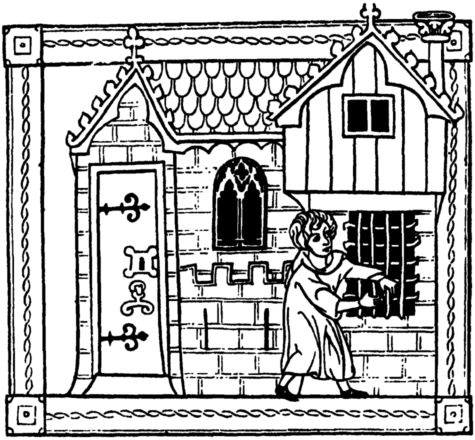
10

THE IRON AGE

MASTERS OF METAL

TO the ancient races of the earth iron was literally a heaven-sent metal : it was known only in the form of meteorites and was regarded as more valuable than gold. Somehow its malleability when heated became known, probably accidentally when a camp fire was lit on an outcrop of ironstone, and by 1000 B.C. it was being fashioned for industrial and religious uses. Iron was known in prehistoric Britain and, if the story of Boadicea's knife-equipped chariots is true, had reached a fairly high peak of craftsmanship by the time of the Roman invasion. At this time, too, iron coinage existed in Britain.

Rome developed the British iron industry on a large scale. In the Forest of Dean, in Derbyshire, and Sussex the fires of the Roman-run bloomeries, as they were called, threw a glow on the night sky which was a preliminary flicker of the blaze of the blast furnaces of to-day. The actual manufacture of weapons for the occupation armies was carried on at Bristol, which was also a convenient place for exporting the surplus to the Italian homeland. When the Empire fell and Britain entered a long period of tribal warfare, the smith became one of the most important men in the community. He came after the king or tribal chief and before the mead-maker and the physician in the Anglo-Saxon order of social precedence. The smith was indeed a mighty man. Although his craft declined, so that the Normans, better equipped with armour and weapons of metal, were able to gain a great and overwhelming victory in 1066, its revival in the next few centuries was steady. The ironmongers were an organised body at the beginning of the fourteenth century, for there are details of the standard sizes laid down for the iron rims of cart wheels, when measurement rods were deposited in the London Guildhall, and at the disposal of the ironworkers, whose premises were in the vicinity



44 Wrought-iron door hinges on a medieval house (from a contemporary MS).

of Old Jewry and Ironmonger Lane. The considerable export business which existed was run from warehouses and yards in Thames Street, where bar iron was loaded straight on to the ships bound for all the countries of Europe. The predominance in output of iron for armaments was one reason why this country was able to withstand the onslaughts of Continental powers.

This was realised by her enemies. One of the orders given to the officers of the Armada was to burn down the forests of Sussex and the Midlands, if complete occupation of the country seemed impossible, in order to destroy the iron-making potential of the enemy. Spain had good reason to know of the quality of the English cannon before the Armada sailed, for many of her vessels were equipped with English-wrought armament, despite the fact that Spain herself had large supplies of iron ore. Sir Walter Raleigh protested about the matter in Parliament, saying : " I am sure heretofore one ship of her Majesty's was able to beat ten Spaniards, but now by reason of our own ordinance, we are hardly matcht one to one."

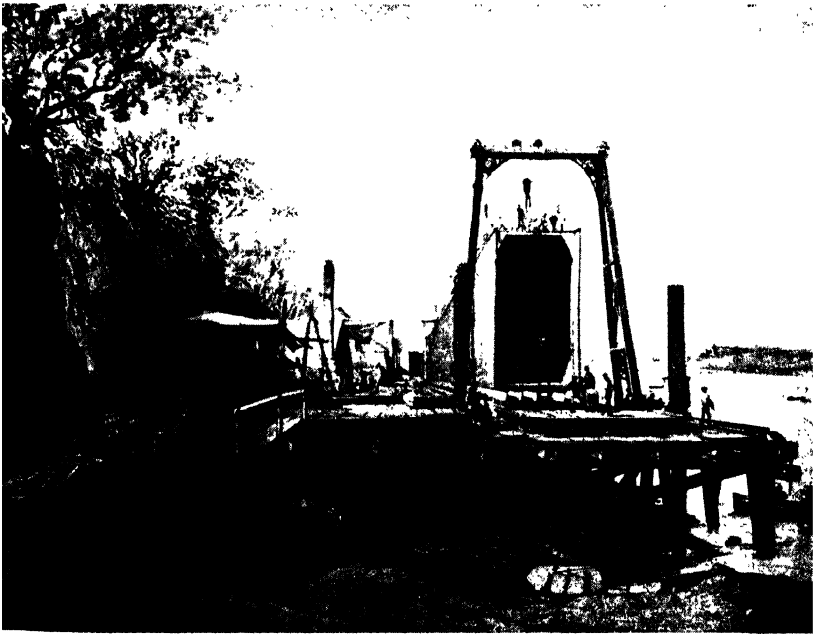
The supremacy of English ironwork and ships in the sixteenth century was not obtained without heavy costs. The demands for timber for shipbuilding and to feed the furnaces were tremendous, and during Elizabeth's reign the despoliation of our forests in Sussex was so alarming that many restrictive laws were passed. Before the days of the Romans this area had been covered by one of the country's greatest forests, named by the invaders Anderida Silva, and in A.D. 893 the *Saxon Chronicle* gave its dimensions as 120 miles by 30. At the end of the sixteenth century there were still 200,000 acres, but the forty-two forges and the twenty-two furnaces of the area which gave work to 50,000 men were fast hacking them away. Some idea of the colossal demands on our wood resources in order to make iron with charcoal can be gained from the fact that one forge at Lamberhurst, producing a mere 5 tons of iron a week, needed 200,000 cords a year to keep its furnace going. Some of the more enterprising Sussex ironmasters, seeing the danger, moved to other areas, notably to Aberdare and Merthyr Tydfil.

The crisis came to a head in the middle of the seventeenth century, when shortage of timber near the iron ore areas and the restrictive legislation on felling trees which the authorities were compelled to pass almost extinguished iron manufacture. Merchants began importing iron from Sweden, Spain, and Germany. The few surviving English ironfounders were alarmed at the development and began experiments with the "sea coal" then coming into use for domestic heating. A German-born mining engineer, Simon Sturtevant, was the first to patent a method of using coal to smelt iron ore, but he does not seem to have had any success, and the patent was cancelled. Then, in 1620, Edward, Lord Dudley took out a patent "for melting iron ore, making bar iron etc., with coal in furnaces with bellows" which marks the beginning of the Second Iron Age. The method was the work of his illegitimate son, Dud Dudley, born in 1599, one of a numerous family born to Lord Dudley and the woman described as his concubine, quite a normal social arrangement in those times. The town of Dudley was a great iron-working centre, and it has been established that 20,000 smiths normally worked in a ten-mile radius of Dudley Castle, though many of them were often out of work through lack of timber for the furnaces and fires.

Young Dud, wandering about his father's estates, must have

45 Tyneside industry in 1835: the Lymington ironworks.

46 Constructional work on Telford's iron bridge across the Menai Straits.

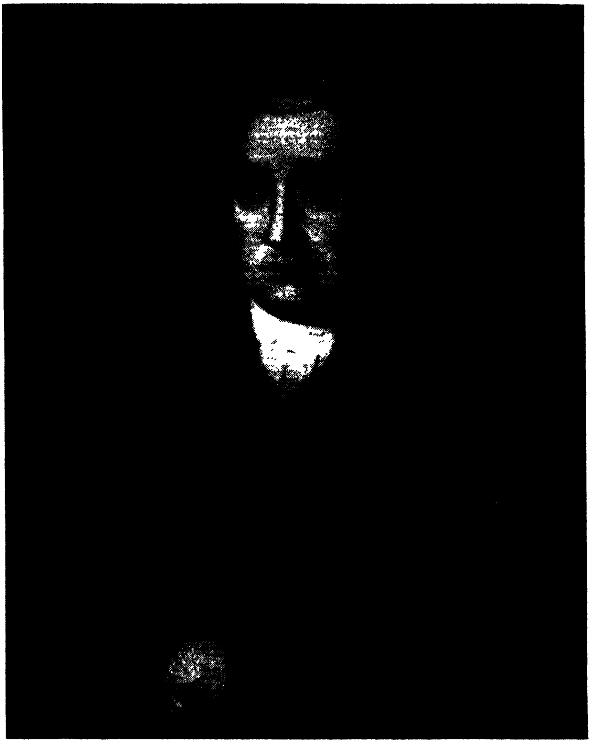


seen scores of iron workings where the coal seams had to be removed before the iron ore was revealed, and doubtless this juxtaposition of two valuable substances started the train of thought which eventually brought him fame if not wealth. He appears to have been a great favourite with his father and was well educated, going up to Oxford until he was twenty, when his father asked him to take control of an iron works at Pensnet, Worcestershire. It was here that he coked coal and then used it in the place of charcoal, and the method was so successful that he asked his father to obtain a patent.

The new system was then used at Cradley, Staffordshire, and some of its products were sent to the Tower of London for testing. The ensuing favourable report so alarmed the ironmasters and their tree-fellers, already facing ruin from foreign competition, that several attacks both on the furnaces and Dudley took place. Then, on 1 May 1621, abnormal rain caused a flood which destroyed the Cradley works completely, much to the delight of his competitors. At considerable expense, he rebuilt the furnace, whereupon, by adroit legal juggling, his rivals fastened a series of lawsuits on him which caused his eviction and he had to move once again, this time to Himley, where he made pig iron.

As he met with heavy opposition from the ironmasters who could forge his product into bars, he himself then erected a large furnace at Hasco Bridge, near Sedgeley, which was soon producing 7 tons of iron a week, by far the greatest output in the country's history from an individual concern. This was too much for his enemies. Timber-fellers, charcoal-burners, and blacksmiths were organised into a mob and an attack was launched on Hasco Bridge. The place was completely destroyed, Dudley was ruined, and later thrown into prison for debt. There he remained until a petition to Charles I provided a pardon, while at the same time his patent in the coal process was confirmed.

Before he could begin work again, civil war broke out and Dudley joined the ranks of the Royalists. During hostilities Dudley seems to have been the genius behind the production of arms for the King's forces, at least until the iron-making



47 John Wilkinson, a great rival of the Darby family and owner of a great cannon foundry and boring mill.

zone around Worcester fell to Cromwell in 1646. Two years later he was taken prisoner, but managed to escape, only to be caught in London and condemned to death. Once again he escaped, though wounded in the leg by the guards before he got away, and eventually he struggled into Bristol, where his wife was hiding. At the end of hostilities, Dudley discreetly emerged into business life once again and managed to interest a couple of Bristol merchants in financing an ironworks. The construction proceeded until Dudley, who had an uncertain temper at the best of times, fell out with his partners and the work was abandoned. He had to wait until the Restoration to regain some of his past honours, although, through corruption at Court, he failed to retain his patent. However, he set down his claim to be the pioneer of iron-smelting with coal in a treatise entitled *Metallum Martis*, published in 1665. He was now an old man, and he appears to have been content to live in retirement at St. Helen's, Worcestershirc, until his death in 1684.

In the vital time of his life, when great financial rewards might have been his, Dudley was on the wrong side in the Civil War. By contrast, another of the pioneers of the time had joined the Parliamentarians and was able to prosper as a result. His name was Andrew Yarranton, born at Astley, Worcestershire, in 1616. Before the outbreak of war he was a linen draper ; afterwards, with rewards for his part in the victory of Cromwell, he set up an ironworks near Bewdley which was a considerable success. On the Restoration he was imprisoned for a couple of years, during which time he developed most imaginative plans for building canals to overcome the transport difficulties he himself had experienced as an ironmaster. When he was released some of his schemes were put into operation, though he was far ahead of his time, and there was hardly the traffic to justify the huge engineering works he envisaged. It is noteworthy, however, that the genius of canal construction, Brindley, followed Yarranton's routes very closely some 150 years later.

In 1665 Yarranton made investigations into the manufacture of tinplate, and went to Germany to see the methods there. Surprisingly, no objections were made to his examining everything he desired, and he returned, not only with the details he needed, but with several workmen as well. The combination of Cornish tin and the Forest of Dean iron proved highly successful, most of the work being undertaken at Yarranton's ironworks at Ashley, near Bewdley. The ore which he used had been partially burned by the Romans, for he transported many thousands of tons of it from dumps near the walls of Worcester, taking it by barge along the Severn to his furnaces.

Yarranton made extensive journeys abroad in connection with harbour engineering and investigation into canal construction, and he found the time to write various works on political economy and trade matters. The date of his death

48 John Wilkinson's iron foundry.

is unknown, although he lived till past the age of seventy.

Whether Yarranton actually used coal is uncertain. In any event, both he and Dudley failed to find the real answer for a charcoal substitute, and while the danger to the forests demanded a substitute for charcoal the needs of industry for very large quantities of iron had not arrived in their lifetime. That situation was dependent on coal and machinery. Pumps to keep the deeper coal-mines free from water needed machines, and machines needed iron. In the same way, the iron for the machines could only come from the production of more coal. It was a circle of supply and demand which created the inventor rather than the inventor creating the industry.

A Quaker named Abraham Darby was the first successful user of coal on a large scale. The son of a farmer, Darby was born at Wrensnest, near Dudley, and in 1700, having married, he went to Bristol, setting up as a builder of malt-kilns and as an iron- and brass-founder. In the depressed state of the home industry at that time, most of the household pots of cast iron came from Holland. Darby found out the method of manufacture, and in 1709 bought an ancient smithy at Coalbrookdale, Shropshire, to make these pots himself. To eke out his wood supplies, he used peat and coke, and gradually he used nothing but coke, building up a large business until his death in 1717. Although his children were very young at the time of his decease, the foundry remained in the family, and in the course of a few years Abraham Darby the Second was in charge. This man's daughter married a Bristol man named Richard Reynolds, who took over the Coalbrookdale works in 1763. This was one of the largest concerns in the country, the biggest rival being the Broseley foundry of John Wilkinson, "the father of the English iron trade" who specialised in the construction of cannon and in boring mills. At this time coal was being used exclusively for the smelting of ore, but the second process of converting the pig iron into malleable or bar iron was still carried out with charcoal. As the production of pig iron had been rising steadily—it was 17,000 tons in 1740 and was three times as great by the seventh decade of the century—the old problem of wood shortage again became acute.

Reynolds recorded the experiments to use coal at the second stage of iron production in a letter he wrote in 1766 :

> I come now to what I think a matter of very great consequence. It is some time since Thos. Cranege, who works at Bridgenorth Forge, and his brother George, of the Dale, spoke to me about a notion they had conceived of making bar iron without wood charcoal. I told them, consistent with the notion I had adopted in common with all others I had conversed with, that I thought it impossible, because the vegetable salts in the charcoal being an alkali acted as an absorbent to the sulphur of the iron, which occasions the red-short quality of the iron, and pit coal abounding with sulphur would increase it. This specious answer, which would probably have appeared conclusive to most, and which indeed was what I really thought, was not so to them. They replied that from the observations they had made, and repeated

49 The first iron bridge in the world : built to the order of Reynolds and Darby at Coalbrookdale in 1777–9.

conversations together, they were both firmly of the opinion that the alteration of the quality of pig iron into that of bar iron was effected merely by heat, and if I would give them leave, they would make a trial some day. I consented, but, I confess, without any great expectation of their success ; and so the matter rested some weeks, when it happening that some repairs had to be done at Bridgenorth, Thomas came up to the Dale, and, with his brother, made a trial in Thos. Tilly's air-furnace with such success as I thought would justify the erection of a small air-furnace at the forge for the more perfectly ascertaining the merit of the invention. This was accordingly done, and a trial of it has been made this week, and the success has passed the most sanguine expectations. The iron put into the furnace was old Bushes, which thou knowest are made of hard iron, and the iron drawn out is the toughest I ever saw. A bar

> 1¼ inch square, when broke, appears to have very little cold short in it. I look upon it as one of the most important discoveries ever made, and take the liberty of recommending thee and earnestly requesting thou wouldst take out a patent for it immediately. . . . The specification of the invention will be comprised in a few words, as it will only set forth that a reverberatory furnace being built of a proper construction, the pig or cast iron is put into it, and without the addition of anything else than common raw pit coal, is converted into good malleable iron, and, being taken red-hot from the reverberatory furnace to the forge hammer, is drawn out into bars of various shapes and sizes according to the will of the workmen.

This development in the use of coal and the consequent increase in both quantity and quality of iron made the Coalbrookdale works the finest in the world. Reynolds saw many of the machines of the new age developed and built at his works or made elsewhere with his metal. It was there that the first iron rails were laid down to replace the wooden guide planks, and the first iron bridge was built (erected in 1777–8 over the Severn for the benefit of the hundreds of employees in the ironworks).

Reynolds was as fine an employer as other members of the Society of Friends who became great industrialists later. His treatment of his employees boded well for the new factory era, even if in the event his example was not followed. Although the twenty miles of railway within the works, with the sixteen steam engines, nine forges, and eight furnaces, were smearing the countryside with the dirt of the industrial age, he saw to it that natural beauty was the right of his workmen. At Madeley, a local beauty spot, he laid out extensive walks through the woods on Lincoln Hill for the use of employees and their families. Once a year the clerical staff and their families were invited to a day on the Wrekin, and in London, Coalbrookdale, and his native town of Bristol he had agents whose sole job it was to discover cases of distress and relieve them. When he died at the age of eighty-one in 1816, one of the first great industrial magnates of the Revolution,

50 A contemporary sketch of Bersham Iron Works, Denbighshire, c.1760.

thousands of the poor in Bristol voluntarily joined the funeral procession to mourn a man of iron who was also a man of supreme gentleness and humanity.

Coalbrookdale solved the problem of increased iron production. It did little to improve quality. Up to the time of the Napoleonic Wars quality was so variable that Government departments prohibited the use of English iron. As late as 1791, 70,000 tons of iron were being imported from Sweden and Russia, only a little less than the production of both England and Scotland. One of the buying agents for the Royal Navy, Henry Cort, who dealt in anchors, armament, and similar ships' supplies, began to wonder why this state of affairs should exist.

Cort was born in 1740. His early career is unknown, but by 1775 he was a wealthy man and in a position to retire from business in order to dabble in a trade of which, so far as is known, he had no practical experience. He went to Portsmouth, and at Fontley, near Fareham, he started a small forge. By 1784 he had two patents granted to him covering every stage in iron-making. His great contribution was the puddling process, in which the crude pig iron was placed in a reverberatory furnace and covered with an oxide of iron. The oxide of iron reacted on the carbon in the pig iron, which was not heated sufficiently to melt it, and a tough, malleable substance was left.

For once an inventor found that his device was neither ignored nor feared. Ironmasters hurried to Fontley, were impressed with what they saw, and adopted the Cort system on a royalty basis. These were soon yielding £27,500 a year, while Cort's own iron was specified for naval contracts. All might have been very well indeed but for a major financial scandal. Cort had a partner named Jellico whose father, a naval paymaster, had advanced the money for the experiments. On the old man's death it was found that some £39,000 had been filched from the public funds. Cort's assets and patents were taken over by the Government, and the inventor was made bankrupt. A little later he and his family of twelve children were in severe straits and friends obtained a small pension for him. Cort died at Hampstead in 1800, a man broken in health and spirit. Whether he knew of the dishonest source of his capital or not is not clear. Very possibly he did, and his conscience was as elastic as most of those connected with supplies for the armed services at that very corrupt period. Probably the money was regarded as a loan (the invariable excuse of the embezzler), though in this instance there would have been little trouble about paying it back if the old man had not so inopportunely died. The Government hopelessly mishandled the matter, denying both the public exchequer and Cort the revenues from the invention, as the ironmasters using the Cort process paid no more royalties to anyone.

The indirect advantage of the scandal was, of course, very great. Cort's methods were copied everywhere. Next to coal, iron ore was and is the chief mineral asset of an industrial civilisation. With a greater vision than most men of his time, Lord Sheffield said that Watt's steam engine and Cort's iron puddling system more than offset the loss of the thirteen American colonies. He could not then know that in the United States were sources of iron ore which to-day represent one-third of the world's supplies, the major factor in that country's emergence into world industrial supremacy. But he did have a visionary glimpse of the gigantic appetite of the new age in which pig iron output would reach 120 million tons a year.

11

A FRAGILE ENGLISH HERITAGE

THE STORY OF POTTERY AND GLASS

FOOD utensils are a necessity in the most primitive communities. Prehistoric Britain was no exception, and the potter's craft was known from very early times. The equipment of the prehistoric potter was simple ; in this country his raw materials were easily found, and he was probably one of the earliest itinerant craftsmen, wandering from place to place to make bowls for any community large enough to justify a day or two of work. Later, with production possible on a larger scale, he settled down at various places where traces of his work have been found by archæologists. By the time of the Roman invasion there were, for example, extensive potteries in the Upchurch marshes of the Medway. The Romans set up many more, and during their occupation of the country ceramic utensils must have been within the reach of most people. The principal Roman potteries were at Peterborough and in the New Forest, and there was also a large one near the present site of St. Paul's in London.

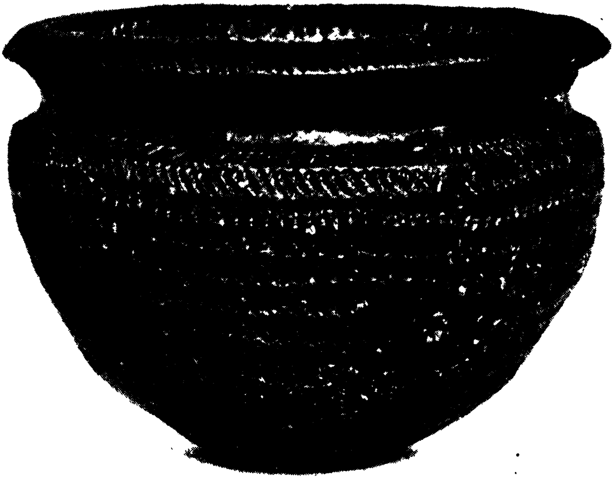
In the Dark Ages which followed, the craft of the potter fell on evil days. The division of the country, the restrictions on travel from one area to another, and the immigration of Saxons, Angles, and Danes, who preferred utensils of metal or wood, were some of the reasons. The poor quality and restricted output of pottery lasted for centuries. Such pieces as have been found are without character until the seventeenth century—with the possible exception of some of the drinking vessels and plates of the Tudor period. Very soon after this the improved economic conditions of the land created a demand for pottery which was met by local craftsmen. One of the busy areas was Burslem, which has a tradition for ceramic manufacture going back to Saxon days, when the name of the place was Bwlwardesloem, a word-combination meaning

" the spot where is quarried and used clay for pots ". One of Burslem's most noted manufactures was a butter-pot used as a standard measure by farmers. In 1661 an Act of Parliament was passed to control the size of these pots ; they were not to weigh above 6 lb. and were to be made so that they contained 14 lb. of butter.

By 1672 the pottery industry must have been fairly large, for it could justify a petition to the King asking for a prohibition of the imports of " any kind or sort of painted wares whatsoever (except those of China and store bottles and jugs) by the way of merchandise ".

This was undoubtedly an attempt to overcome the competition of the tin-glazed Delft ware made in enormous quantities at Haarlem in the Netherlands and easily the best-known " utility crockery " in Britain. About its only rival in the South of England was the slipware made at Wrotham, Kent. This consisted mainly of tygs (a type of tall cup), piggins (a ladle), and cradles (a basket-shaped dish used at christening feasts). Some time later a potter named John Dwight began the manufacture of stoneware at Fulham. It was called Cologne ware and became very popular among the wealthy classes.

Dwight was a Dutchman who had settled in England. He began work in 1671. Two compatriots of his arrived in 1690 and were the real founders of the modern ceramic industry in this country. On the advice of Dwight, who had made a careful study of the clays of the country, these two men, the brothers Elers, chose Bradwell Wood, near Burslem, as the site of their pottery. Their methods caused a sensation among the English potters, who had been content to follow the rough-and-ready processes of their forefathers. The Elers strained their clay ; they used metal dies to mark decorative effects, and they paid close attention to colour. But the most obvious improvement was in the glazing. Nothing like it had been seen in England. The process caused a large amount of smoke from the kilns, and this, as much as the quality of their ware, induced the eight or so master potters of the Burslem area to go along to Bradwell Wood to see what was happening. They were not able to get near the huts or kiln.



51 A Stone Age food-bowl, decorated with a " maggot " pattern, made by pressing a piece of twisted corn on to the damp clay.

From this incident comes one of the earliest—and maybe the original and authentic—version of the " spy in the factory " legend which crops up over and over again in the story of invention. John Astbury, by feigning idiocy, is supposed to have got inside the Elers works and to have seen that the glazing was achieved by scattering salt over the pots at a certain stage of the firing. If this was the first occasion that the secret got out, then the Elers had a very good run for their money, for Astbury was only three years old when the Dutchmen began work.

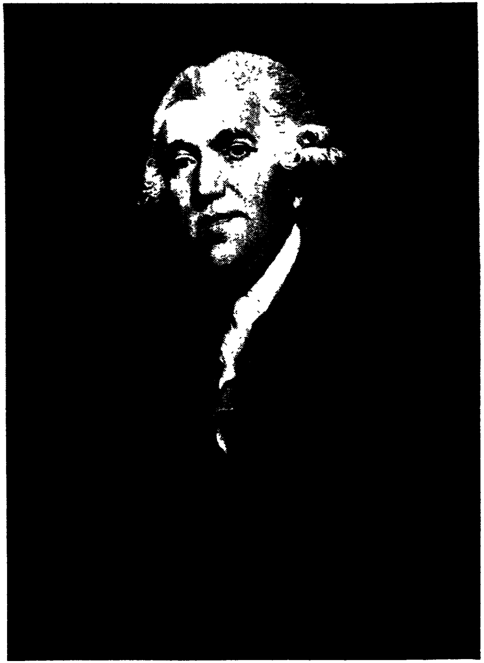
In any event, Astbury has a better claim to fame than snooping into a rival's trade secrets. He was the first to manufacture the cream-coloured pottery which is to be found in every home to-day. He was the potter who discovered that flint was an ingredient to work into the clay to get a hard tough china of a delicate thinness. This he is supposed to have thought of when his horse had an affection of the eyes. The ostler's remedy was to plunge a red-hot flint into a little water and to blow the white powder which came off the cooling stone into the horse's eyes. Whatever efficacy this may have had for the ailment, it was certainly a new substance for Astbury to try mixing with clay, and this he did with immediate success.

Astbury was a relation by marriage of the greatest name in ceramics : Wedgwood. Astbury's brother married the aunt of the boy who was to launch mass production in Britain and build up an entirely new export business. Although the effect of enormous quantities of cheap Staffordshire pottery arriving in every country in the world caused most European nations to prohibit imports and the remainder to impose heavy tariffs, the ware was so highly valued that by the end of the eighteenth century five-sixths of the production of pottery in Staffordshire were exported. One man was responsible for the emergence of this vast industry in the matter of a few years.

The Wedgwood family had a long tradition of the potter's craft. Josiah's great-great-grandfather, Gilbert Wedgwood, had been in the business in the seventeenth century, and so had his descendants. It was not usually a very profitable form of occupation. Potters existed in most villages where a deposit of clay was available. After making a supply of pots, they would tramp round the district with a load of ware in a large basket slung on the back, selling from door to door. If business was good, the potter's wife and children were almost continually employed in this way, while the man stayed at home producing pottery which was certainly not very artistic and usually of poor quality. Everyone who could possibly afford it, bought Delft ware in the seventeenth century, while the wealthy who wanted something decorative bought the high-priced porcelain of Germany, France, and China.

Josiah was born on 7 July 1730, the youngest of thirteen children. His father died when he was nine years old, and this meant that schooldays for the boy were over and he had to go to work. He was apprenticed to an elder brother, Thomas Wedgwood, and began work as a thrower, which was fine training if almost impossibly heavy work for a lad of his age. He had never been strong ; then he caught smallpox, which left him with knee weakness. As a result, he was unable to work at the potter's wheel and he devoted his time to a

52 The Churchyard Works, Burslem, of Josiah Wedgwood, started by his great-grandfather in the reign of Charles II.



53 Reynolds' portrait of Josiah Wedgwood, the man who "converted a rude and inconsiderable manufactory into an elegant Art".

study of the artistic and scientific side of pottery. He experimented with colours and decorations and made notes on the different types of clay, the temperature of the kiln, and so on. This academic work annoyed his brother, and the apprenticeship was broken in 1749, when Josiah was nineteen, though he continued to work for him as a journeyman. Then, when he reached the age of twenty-one, he inherited £20 left to him by his father. With this modest sum, plus what he had managed to save, he went into partnership with a man named Harrison who was as poor as he was. They made earthenware knife-handles. Their work came to the notice of Thomas Wheildon, a pedlar who had turned potter and become rich and influential, and who encouraged young potters of real enterprise. Wedgwood went into partnership with Wheildon for five years, with works at Burslem.

In 1759 Wedgwood launched out on his own, with two small potteries at Churchyard Works, Burslem, and at Ivy House. He personally supervised every facet of activity at these places and divided the operations so that one man worked at only one part of the process. This caused some objections at first, for hitherto the artisans did much as they pleased, changing from one job to another according to the demands of the occasion. After a time, however, the workmen saw that the division of labour resulted in a greater output and better wages, and they were well content with the novel arrangement. Wedgwood's pottery was now well on the way to success.

About 1761 a third factory was needed—the Brickhouse Works. Then came the Bell Works, so called because Wedgwood built a turret from which a bell rang to warn the workpeople of the district when it was time to start and stop work, the forerunner of the factory siren of to-day.

In 1762 the name of Wedgwood was assured of a place in the artistic world of craftsmanship with the production of his queen's ware, designed to mark the birth of a baby to Queen Charlotte. While this type of special ware was being made, vast quantities of beautiful but inexpensive china were also being produced, and for the first time the British people could buy crockery which was strong, yet delicate, beautiful,

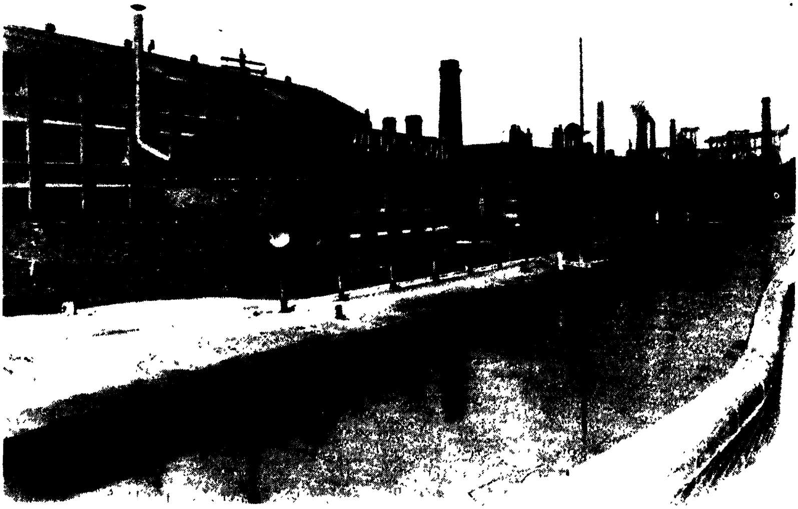
54 The Wedgwood family in the grounds of Etruria Hall in 1780. Josiah is seated on the extreme right with his wife. Josiah II is the 11-year-old boy on the pony in the centre.

and useful. It was Wedgwood's boast that twelve dozen of his plates could be stacked one on top of the other without their toppling over—a testimony indeed to their evenness and similarity of shape.

At the age of thirty-eight his knee gave serious trouble and his leg had to be amputated. It had little effect in stopping his ambitious plans. A year afterwards the finest industrial plant of its age was opened and named Etruria, in honour of the classical pottery which Wedgwood always admired. By this time he had a partner named Thomas Bentley, a Liverpool merchant who was an enemy of the slave trade years before the world's conscience was stirred against the traffic in human beings. Bentley was a social reformer in his own town, a man of culture, and a hard-headed business man into the bargain. With Bentley looking after the merchandising side of the business and Wedgwood concentrating on production, the Etruria Works' prosperity increased at a spectacular rate. A magnificent mansion was built for the man who had begun his career as a thrower at nine years of age; at the same time hundreds of workers' houses were built to a standard which brought applicants for jobs from many parts of the country.

Staffordshire has had few sons who have done more for their homeland than Wedgwood. He built ten miles of turnpike roads in the Potteries and he assisted in the construction of the Trent-Mersey Canal. These works were partly to help his own traffic. He knew all too well the damage caused by abominable roads from the days when he sent wagon-loads of china to Liverpool for transfer-colouring, but the general result of his road and canal work was to benefit the community generally.

The whole world soon recognised the value of Wedgwood pottery. While the kilns poured out masses of perfect china (Wedgwood used to stump through the works smashing anything he considered below standard with a sweep of his walking stick), the owner himself devised objects of art in his ambition to recapture the genius of classical artists and craftsmen, the Wedgwood copies of the Portland Vase probably being the most famous examples of this branch of his work.



55 The Etruria Works as they were until just before the move to the new Wedgwood factory at Barlaston.

He died in 1795 from gangrene of the jaw—an agonising end for a man who had never known what it was to be without pain from the time he caught smallpox as a child. Gladstone, on opening the Wedgwood Museum at Burslem in 1863, summarised Wedgwood's work in saying that the potter was " the greatest man who ever in any age or any country applied himself to the important task of uniting art with industry ". The founder's high traditions are still maintained by his firm.

It will be appreciated that the development of the pottery industry founded by Wedgwood was an eighteenth century event. The supreme position which the Potteries thus held was maintained in the nineteenth century, too ; indeed, so vast and well organised was the trade that it virtually brought the practice of ceramic art to a standstill on the Continent of Europe. For general household use there arrived at this time vast quantities of bone-china, perfected by the second Josiah Spode. The first Josiah Spode, who knew Wedgwood and presumably adopted his methods, began mass production of printed cream ware in the Potteries in 1770, and twenty years later it was a humble home indeed that did not have a few dishes and plates of Spode ware, decorated with cobalt blue transfer designs. When the younger Josiah was able to make enormous quantities of cheap and beautiful bone-china, this extensive ownership became world-wide.

The name of Spode became as famous as that of Wedgwood in the early years of the nineteenth century, and coupled with it must be Minton, whose ware was in the luxury class. The Minton potteries became world-renowned for the production of jewelled pieces which to modern eyes may be a little over-ornamented, but represent a very high standard of the potter's art.

Another great name in the industry is Henry Doulton. The son of a man who made blacking bottles and similar containers, Doulton made both beautiful and useful ware. The latter had the most profound effect on the people of Britain, for the Doulton sanitary stoneware was the main weapon in the war against the filth of the nineteenth-century town. Before his drainpipes were made, sewers were either of brickwork or of wood. Poisonous matter and explosive gas leaked out everywhere.

It is impossible for all but the highly imaginative to realise the condition of the big towns before Doulton's pipes made efficient drainage possible. London was probably better than some of the " mushroom " towns of the industrial areas, but a few excerpts from official reports indicate the savagery of life in the new and uncontrolled civilisation of the industrial era.

The bulk of London's population (1,874,000 in 1841) lived in a vast slum. The houses were often made with walls only half a brick thick, and the floors were of mud. The famous —or infamous—area of the Rookery, which was a maze of alleys, courts, and yards in what is now the Charing Cross Road and New Oxford Street area, had between two and four families in every room, cellars included. Only one worker's family in six could afford a room to itself in the whole town. Large numbers of these families kept a pig, partly because of the value in selling it, and also because it cleaned up the filth.

Drains are unpleasant; the lack of them is unpleasanter.

And drains were rare in those days. Despite the statement that " London's drainage is unrivalled for extent and construction " which a writer made in 1840, it merely makes one wonder about other towns, whose records, maybe happily, are unwritten. In Parliament, where the stench of the Thames made it unwise to have the windows open, sanitary legislation was usually deferred owing to the cost to the various parishes, landlords, and so on. Then in 1847, when famine was helped by plague, the Metropolitan Commissioners of Sewers were appointed. In the same year cholera struck London. By 1865 the sewage system was fairly extensive in the Metropolis, and it poured its filth into the Thames through sixty-four openings. In that year it was suggested that the sewage must be pumped down below London, for the tide caused all drains to be blocked for six hours a day. The First Commissioner of Works promptly vetoed the idea. But public opinion was aroused and Parliament was forced to pass an Act two years later which abolished the veto.

It is of little wonder that public anxiety was aroused. In 1840 some houses had water closets, but for the poor the usual thing was the privy midden. It was often used by as many as 100 persons, and as in many areas the contractors who emptied it had to be paid for their services, the emptying was left as long as possible. Better-class houses had cesspools. These were under the house and seeped into the cellar and nearby well. On London's clay they had to be frequently pumped out. The inhabitants of Gracechurch Street in the City used to have theirs pumped out each night, and the black stream seeped gently down the road into the Thames, a few hundred yards away.

Conditions like this before the Doulton pipes were laid below the surface of London exacted an enormous toll in human life. It meant that one child in six died in its first year and one in three before its fifth year. It meant that the death-rate for the whole country was 23 per 1,000, with the slums leading the way to destruction. In Edinburgh in 1840 the rate reached 39 per 1,000, and in some industrial towns the average age at death was thirteen. Just what was the child sacrifice is shown from the fact that the number of people dying under twenty (per 10,000 deaths) in an agricultural area such as Rutland was 3,736, in London 4,580, in Bradford 5,896, and in Stockport 6,133.

Doulton has his place as one of the great contributors to the well-being of the nation even though he is to-day far better known as the maker of beautiful china—a more pleasant subject than his stoneware drainpipes, but not nearly so valuable.

An industry which has some parallels with ceramics is the manufacture of glass. Like the craft which has just been described, the making of glass is an ancient art, being known to the Egyptians as early as 1700 B.C. No details of glass manufacture in England before the thirteenth century are discoverable, but in 1240 Laurence of Chiddingfold supplied coloured glass for Westminster Abbey, and there are slightly earlier examples in the country's churches, notably Saxon glass in a chancel window of a church at Jarrow. Chiddingfold was the centre of the glazier's activity for the London market, but it also existed in many other areas, notably Staffordshire and the Cotswolds. By 1328 a Glaziers' Guild had been formed in London, indicating that the workers were numerous and important enough to justify official recognition. The whole business of making glass was regarded as something akin to magic, and the craft was maintained as a mystery. The trade flourished with the help of religious refugees from Venice, France, and the Low Countries, and received a strong impetus with the building of Tudor houses, where, for the first time, windows using plenty of glass were included in the design.

The arrival of the Venetian craftsmen in England must have been a tremendous blow to that wonderful centre of glass-making in Italy. For nearly 400 years Venice had guarded its secrets. The factories were isolated on the island of Murano, the workers sworn to secrecy, and their attempted emigration punishable by death. Even scrap glass was protected by capital punishment for anyone who allowed a few pieces to get outside the island.

At the end of the sixteenth century English glass-making received a temporary set-back when the needs for timber for naval construction resulted in glass-makers being prohibited from using wood for their furnaces. Fortunately, Thomas Percivall's development of coal furnaces provided a ready solution, and the glass works moved from the villages of Oxfordshire and Sussex to the big towns, where coal barges could deliver the new fuel or mines were adjacent to the works. Many patents were taken out in the sixteenth and seventeenth centuries for using coal for glass-making, but the processes did not gain much ground because the fumes from the burning coal spoiled the glass until someone fitted lids on the crucibles. With the legal ban on wood fuel for the glass furnaces, the Stuarts saw the chance of selling a monopoly in making glass with coal, and when Sir Robert Mansell had spent a major part of his fortune in perfecting the process he then had to pay James I £1,000 a year for the monopolistic rights. It was a good investment, as most of these monopolies were, and in the middle of the seventeenth century Mansell was employing 4,000 craftsmen in his glassworks on the Tyne, and he retained his rights for some thirty years, during which time Tyne glass was so plentiful and cheap that all but the very poor could afford at least one window in their homes.

The glass was not very clear until, in 1675, George Ravenscroft produced flint glass. His process was really a re-discovery, for the Romans had used lead as a flux, and so had the Venetians. Ravenscroft used a large proportion of lead oxide, which gave a harder and clearer glass than any previously known in Britain.

Since that time the British glass industry has been in the forefront both as regards quantity production of ordinary glass and in the scientific field. Nowadays, one furnace, melting together mountains of sand, soda, and limestone, can produce 160 square feet of glass per minute continuously day and night, year in and year out.

Optical glass, threads of glass with a diameter one-tenth that of human hair and the tensile strength of steel, glass bricks, and a score and more of equally diverse products are proving that this ancient material can more than hold its own against the new rival, plastic.

12

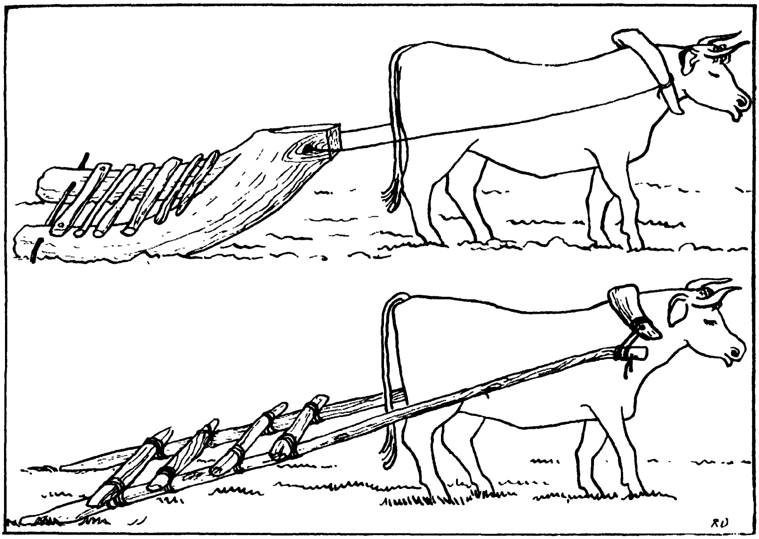
RIDING ON AIR

PROCESSING OF RUBBER

FAR up the River Amazon, scattered over more than a million square miles of Brazil, are more than 300 millions of trees called *Hevea brasiliensis.* For untold centuries before the Spanish and Portuguese explorers and missionaries pierced into this territory, described sometimes as a green hell and sometimes as an earthly paradise, Indians had known of the sap of the *Hevea.* They made it into solid little images for their temples ; they hardened it into bouncing balls for religious ceremonial games ; and they smeared their clothes with it to keep out the rainstorms which sweep the area.

In this, one of the geologically oldest areas of land of the globe, the unrivalled type of rubber tree flourished. The story of the way rubber seeds were taken to the other side of the earth is possibly one of which we cannot be outstandingly proud, for it was robbery. Nevertheless, the result was of inestimable benefit to the world in general and Britain in particular. The electrical and road transport industries could hardly have expanded as they did without enormous supplies of rubber grown in other countries.

Brazil, which understandably wanted to retain the monopoly that Nature had bestowed on her, could never have organised supplies on the scale of the Eastern plantations. This was proved during the Second World War, when a campaign was launched on a military scale to obtain from the Matto Grosso area supplies of rubber to replace those lost to the Japanese. The cost in both money and lives was such that the construction of synthetic rubber factories was shown to be an easier system. Nature has surrounded her rubber forest with an almost insurmountable barrier to large-scale working by man. Air transport, amphibious vehicles, and medical knowledge may make the exploitation of Brazilian wild rubber a feasible task in the future ; seventy years ago it was an impossibility.



56 Sledges like these served humanity until the wheel was invented. Virtually no improvement followed until the development of the pneumatic tyre.

The man who had the dream of producing rubber in the tropical areas of the British Empire was James Collins, Curator of the Physic Garden of the Apothecaries Company. He wrote a brief treatise which aroused the interest of several directors of the East India Company and the Duke of Argyll, Secretary of State for India. A few seeds were obtained from botanists and planted in England and India. They failed to germinate.

Then Sir Joseph Hooker, Director of the Royal Botanical Gardens at Kew, suggested that a friend of his who occasionally sent the Gardens botanical specimens might help. He was Henry Wickham, a trader living at the junction of the Amazon and Tapajos Rivers who frequently went on jungle expeditions.

Wickham agreed to try to send seeds for £1 5*s*. per 100. Just as his instructions arrived, an extraordinary opportunity arose to move the seeds without any delay. A new ship, the *Amazonas*, had arrived on her maiden voyage from Liverpool for a cargo of rubber in exchange for trading goods. The agents had taken the goods into the jungle and decamped, and the ship had no cargo and no means of finding one. On the strength of the letter in his pocket, Wickham chartered the ship on behalf of the India Office and ordered the Captain to move to the mouth of the Tapajos River.

Wickham himself meanwhile set out with two Indians on a fifty-mile expedition up the river. He collected a few score natives and sent them scouring the jungle for the oily seeds of the *Hevea* tree. They brought him back basketfuls, which he carefully dried and packed among leaves laid in long baskets woven from cane by the native women. Then, in a dozen canoes, the precious cargo was paddled down-river to the place where the *Amazonas* was waiting. Within minutes of arrival, the ship moved down the Amazon while Wickham spread the seeds in the hold. At Para, where the ship's papers had to be cleared, Wickham said that she was carrying botanical specimens which would be damaged by delay. His luck held. The ship was allowed to proceed without a search, carrying 70,000 seeds of *Hevea brasiliensis*—a cargo infinitely more precious than any of the masses of bullion which used to go by galleon from South America to the Courts of Spain and Portugal.

When the *Amazonas* docked at Liverpool a special train rushed the seeds to London, and from the terminus to Kew the long journey was completed in a hansom cab. The great orchid houses had been cleared for the seed beds. Out of the 70,000 seeds 2,800 plants were sprouting in a fortnight, and in the autumn of 1876 2,000 of them were shipped to Calcutta and thence to Ceylon and Malaya. It took twenty years for the new plantations to start yielding para rubber on a big commercial scale. With that supply the inventions of the rubber tyre and waterproof clothing could be exploited.

The first and true inventor of the pneumatic tyre was Robert William Thomson, born at Stonehaven, Kincardineshire, in 1822. His father, who owned a small factory, hoped that his boy would enter the Church. This meant studying the classics, but young Rabbie hated schooling and at the age of fourteen he was sent to Charleston, U.S.A., to become an assistant to an importer. This was unsuccessful and within a short time the youth was back in Scotland working in factories in Dundee and Aberdeen, where he showed a flair for mechanical inventions. Electrical firing of detonators in mines, a ribbon saw, and a fountain pen were some of his ideas which were adapted by industry, the pen being chosen as an exhibit for the Great Exhibition of 1851.

In his early twenties he helped to construct various railways in Scotland, but when the " steam engine bubble " burst and the innumerable crazy financial schemes were abandoned he returned to research work. Thus it was that on 10 June 1846 he was able to complete his specification at his house in Adam Street, Adelphi, London, of " an improvement in carriage wheels, which is also applicable to other rolling bodies ".

Two months later a brougham fitted with " elastic tyre wheels " was running in London. The *Mechanic's Magazine* of the time reported :

> The attention of the visitors to the parks this week has been attracted by the appearance among the crowd of gay equipages, of a brougham with *silent* wheels—so silent as to suggest a practical inconsistency of a most startling character, between the name and quality of the thing. The tyre of the wheels consists of an elastic tubular ring, made (we believe) of caoutchouc, inclosed in a leather case, and inflated with air to any degree of tightness desired. The motion of the carriage is exceedingly easy. We are informed that it has now gone about a hundred miles, over roads of all sorts, even some that are newly macadamised, and that the outer leather casing is (contrary to what might have been expected) as sound and entire as at first, not exhibiting in any part of it the slightest tendency to rupture. The inventor is Mr. R. W. Thomson.

And in March, 1847, the same journal published an article :

> THOMSON'S PATENT AERIAL WHEELS
>
> We gave a slight notice of these wheels at the time of the first appearance in public of a carriage fitted with them, about six months ago, and since then we have been favoured with a full explanation of their mode of construction, and also had an opportunity of personally testing their capabilities.

> The reader will perhaps recollect that the peculiarity of these wheels consists in their tyres being formed of elastic tubular rings, made of India rubber (vulcanised) and inflated with air to any degree of tightness required. The most obvious advantage—indeed, the only one which, at first sight, would seem likely to result from the substitution of an elastic for a non-elastic tyre—is a diminution of noise ; and hence it was that we were led in one former notice of the wheels to characterise them as "silent" rather than as being distinguished for any other property.
>
> It has been so long regarded as a settled thing, that friction is least with hard substances, and greatest with soft, that, by a natural, though not perhaps strictly logical, course of induction, we inferred that, though in this case the noise might be less, the friction, and consequently the tractive power required, would be greater. We must candidly own that we little expected to find the very reverse of this to be the fact. Yet so it is. Experiments very carefully conducted, and which we have ourselves repeated and verified, prove incontestably that the friction and draught are diminished to a very great extent by the use of these elastic wheels.
>
> It stands thus established, that we have here a wheel which not only makes little noise, or, more strictly speaking, perhaps, which is in itself noiseless, for to us it seemed as if all the noise were occasioned by the rumbling of the body of the carriage, and parts in connection with it—but which requires from one to three times less tractive power than a common carriage, and which must consequently be much less subject to wear and last proportionately longer.
>
> The wheel-tyres of the carriage with which we made our experiments were stated to have travelled upwards of 1,200 miles on all sorts of road ; yet we could not discern in them the slightest symptoms of deterioration or decay.

Two years later the journal again returned to the subject

We have recently had the pleasure of a drive in the carriage fitted with these wheels. Some improvements have been effected since we gave a description of them in a former number which are of a very marked character. The leather case for the air tube has been replaced by a case made of a peculiar kind of canvas, manufactured expressly for the purpose ; and on the outside of the canvas, where it is liable to wear from coming in contact with the ground, a band of vulcanised India rubber is placed. The behaviour of the India rubber under this treatment is extraordinary. Not only does it not wear thinner, but the original surface remains wholly undisturbed. A curious proof of this was presented to us, on comparing a piece of new vulcanised rubber with the surface of the rubber on the carriage wheel which had been constantly at work for about two months. The new rubber was marked on its surface by a clearly defined impression of fine cotton (arising, we believe, from its being spread on cloth when in a soft state to form it into sheets) and this marking we found on the wheel as sharply defined as on the new rubber. . . .

Despite the opinion most people would form, on first seeing the wheels, that the draught must be greatly increased by a soft and yielding tyre, the draught is unquestionably very much lessened. We ourselves have tried a series of experiments on the draught by a dynamometer, and are perfectly satisfied of the fact.

The tyres are perfectly elastic as well as soft. They do not sink into loose gravel or soft ground as common wheels do. Nor, on paved streets, do they retard the carriage by receiving constant concussions from every paving stone or other obstacle they pass over—they yield to every inequality, permit the carriage to pass over it without rising up, and the elastic tyre expanding as it passes from the obstruction, returns the force borrowed for a moment to compress the tyre.

We entertain a confident expectation that these wheels will speedily come into general use. The perfect stillness

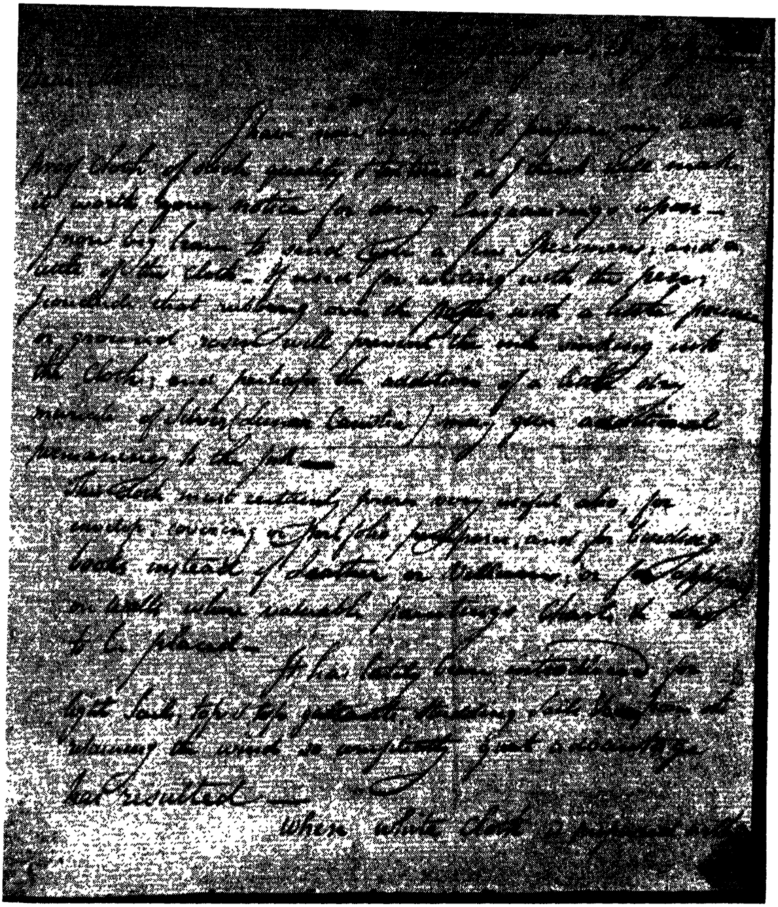
> with which they roll along, places them above any comparison with common spring carriages. The saving of horse flesh will more than repay their additional cost at first; and they can be renewed, we believe, at about the same expense as common wheels.

They were wrong. Pneumatic tyres for horse-drawn vehicles have never become very popular; and, at the time of Thomson's invention, the processing of rubber was too poor to be really efficient.

In 1852 Thomson virtually abandoned his work on tyres and emigrated to Java, where he became an engineer in the sugar plantations. He also found time to invent a new type of hydraulic dock and build a very powerful steam crane. After ten years he returned to his homeland, settling in Edinburgh and devoting his energies to the road steamer, for which he devised solid rubber tyres. They were made for him by the North British Rubber Company and were of enormous size. Four of them weighed nearly 1½ tons, and they were 5 inches thick and 12 inches wide.

His patent on the pneumatic tyre had expired, and he does not seem to have continued with its development, although he used them on his own private carriage. He gave a practical demonstration to the Emperor of Brazil of this use of his Empire's natural product by taking the potentate for a ride in the carriage in 1871. Two years later Thomson, who had suffered from ill-health since his return from Java, died at the age of fifty-one.

The perfection of a process to harden rubber is deservedly ascribed to the American inventor, Charles Goodyear. He was a fanatical inventor—and only the zeal of such a man could have overcome the years of disappointment which beset him. When he began work the entire world used less than 300 tons of caoutchouc a year. Before he died, leaving heavy debts for his widow and six children, one of the greatest industries had been born. Goodyear, through poverty, did not patent his discovery of vulcanisation with sulphur in 1839 until five years later. In that interval a Scotsman had started using the same process. The story goes back some years,



Part of a letter from Charles Macintosh in 1830 reporting on his waterproof cloth, by then suitable for engraving, bookbinding, and sailmaking.

for the problem of hardening rubber had occupied the attention of chemists since the late sixteenth century.

Scotland's contribution was really accidental. A young Glasgow chemist named Charles Macintosh had set up in the business of supplying woollen interests with chemicals, principally a red dye obtained by macerating lichens in ammonia. The latter chemical was obtained in a crude form from the new Glasgow gasworks, where the by-products of gas-making were causing a growing bewilderment as to what could be done with them. Macintosh had to take the coal tar as well, so that he too was worried about the masses of waste once he had separated the ammonia. With the thriftiness of his race, he decided to sell the pitch to the Clyde shipwrights, but this still left both light and heavy oils. The latter eventually found a market among timber merchants as a wood-preserver, but no one wanted the naphtha. So he started experimenting with it, and, remembering the general interest in rubber-processing, he dissolved a piece of raw para in his oil. Then he evaporated it, and was left with a skin of rubber.

Macintosh was, as has been said, closely connected with the woollen industry. Samples of cloth were always lying about his laboratory. He took two pieces, smeared each with his naphtha rubber solution and pressed them together—the first piece of rubberised waterproof fabric, which put the inventor's name in the dictionary.

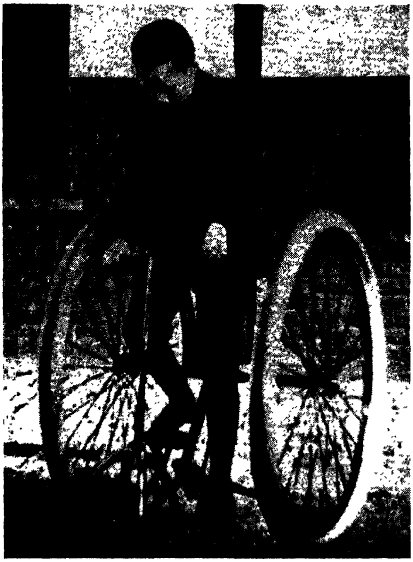
Macintosh patented his process in 1823. At first the Scots, who live in a very wet climate, bought the clothes made with his fabric in great quantities. That was in the autumn of 1823, when temperature was equable. When the weather grew colder the cloth became as stiff as if it had been starched, and when the hot weather came in the summer the liquefying rubber combined with the grease in the wool and stank. It also ran out of the seams.

As Macintosh wrote in his diary shortly afterwards : " The use of the article in the form of cloaks, etc., has of late become comparatively extinct." But it was only comparative. The War Office did not worry about appearance or smell ; it needed a waterproof for the use of the troops, and large orders were placed. Macintosh devoted his whole time to the manufacture of waterproof coats in partnership with two Manchester cotton-spinners, Joseph and Hugh Birley.

Some of the new waterproof cloth came into the hands of Thomas Hancock, a London coach-builder. He realised that it would be useful for the roofs and side curtains on his vehicles, and extremely suitable it proved. This aroused Hancock's interest in rubber, and he seems to have been the first man to sell it in the form of elastic. He cut raw rubber into thin strips and obtained a patent for its use in the wrists of gloves and the tops of pockets to foil the pickpockets, and to be used in shoes instead of laces or buckles.

Hancock began experimenting with rubber solvents himself without succeeding in the discovery of any substitute for naphtha. But when he had obtained a large mass of scraps he remoulded it into one complete lump. This he did by placing all the scraps in a barrel fitted with a crank working revolving teeth. His idea had been to shred the rubber so that the pieces could then be compressed into a block. Instead he produced a soft, pliable, and steaming substance which had moulded itself. From this he began to mix various dry powders into his rubber, and so he pioneered the craft of rubber-compounding. His rubber was far better than that used by Macintosh, and he could produce waterproof material in less time and at a lower cost.

Instead of starting a foolish competition, one man having the patent and the other the best method, Macintosh and Hancock combined forces and soon built up a large business. The partners knew about the work of Goodyear in America, and they had been sent samples of his rubber treated with sulphur. As experts, they knew that all the defects had been overcome and Goodyear had achieved the production of one of the toughest pliable substances in the world. Goodyear did not disclose the nature of his process, and Hancock patented a vulcanisation method using sulphur on 21 November 1843. The claims of America and Scotland to be the first to perfect vulcanisation have never been truly settled to the satisfaction of both sides. It may be suggested that experienced chemists could have analysed the samples sent by Goodyear and discovered what he had done. There is also the irrefutable fact that Goodyear, too poor to take out a full patent in America, let alone England, had nevertheless registered a claim for one with the U.S. Patent Office on 6 November 1841, two years ahead of Hancock. Lawsuits in this country when the Hancock patent was challenged proved to judges and juries on two occasions that it was valid. In evidence, Hancock



58 Johnny Dunlop rides the first pneumatic-tyred tricycle.

59 J. B. Dunlop, still "riding on air" at the age of seventy-eight.

gave a long and detailed account of the years of research which he had conducted and explained step by step his experiments which led to the use of sulphur. It would seem that the fairest verdict is that two brilliant chemists, given the problem of hardening rubber, began a series of patient experiments which led them both to the same conclusion.

Rubber clothing, rubber shoes, rubber insulators sent the young industry well on the road to prosperity, but no one at that time could have foreseen what the internal combustion engine would do for the new substance. They were soon to have a glimpse of the possibilities through the humble bicycle. The forty-year-old invention of Thomson was revived, improved and launched on the market by a Scottish veterinary surgeon, John Boyd Dunlop. It is of interest that there is a coincidence of both time and place between the two great names connected with the pneumatic tyre. Dunlop, born in 1840, was only eighteen years younger than Thomson, and the former's home on a farm at Dreghorn, Ayrshire, was little more than fifty miles from Thomson's house.

John Dunlop was a premature baby, and though this is now known to have no effect on the child, at that time it was thought to jeopardise one's chances of lifelong health. Dunlop believed this, and although he lived to eighty-two, he acted like a semi-invalid all his adult life.

After his education in Edinburgh, he went to Ireland to practice as a veterinary surgeon, aiming to retire at the age of fifty-two if he lived as long. He made a good income in his profession, and was devoted to his wife and two children, a son and a daughter. The son, John, became famous as the person for whom Dunlop made his pneumatic tyre. The boy was rather delicate and the doctor suggested that cycling would be an excellent form of exercise provided he took care not to jar himself too much on the cobbled streets of Belfast.

This set Dunlop thinking how best he could provide a cushion of air to protect his ten-year-old son. His first experiment was on a disc of wood to which he nailed strips of linen to hold an inflated rubber tube. He then fixed the usual metal tyre on a similar disc of wood and tested them both for bouncing and rolling properties. With the difference in performance very obvious, he next fixed a rubber tube in a canvas pocket on the rear wheels of a tricycle. The canvas was then protected by strips of rubber and the whole contrivance was attached to the wheel rim by rubber solution and tape. The tricycle was tried secretly by Johnnie after dark one night in 1888, and on 31 October of that year Dunlop patented his " improvement in tyres of wheels for bicycles, tricycles, or other road cars ". Before this, Dunlop had made two more tyres which were fitted on a bicycle for his son, and they travelled 3,000 miles before they were worn out.

Despite a clever publicity campaign on racing tracks, where the pneumatic tyres easily proved their worth and superiority, the public and the cycle trade ridiculed the new idea, but thanks to the energy of Harvey du Cros, a Dublin manufacturer, the pneumatic tyre was soon being made under Dunlop patents all over the world. Within a year or so, bicycles were equipped with pneumatic tyres as a matter of course, and the first cars were chugging along the roads with them too. The world had started to ride on air—encased in steel.

13

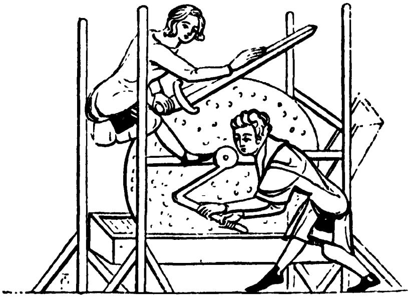
RIVERS OF METAL

PRODUCTION OF STEEL

STEEL is the very fibre of modern civilisation. A nation's industrial strength depends on it in time of peace and her life survives or fails through it in time of war. Steel is not a new discovery. The Saracens were able to sweep into Spain on the power of their swords, and it was the same quality which enabled that amazingly cultured and resourceful race to withstand the onslaught of Christendom on the Holy Land during the Crusades. The patience and craftsmanship which must have gone into the manufacture of the Saracen swords, so strong that they would pierce coats of mail with ease and so keen that they were reputed to have cut a feather floating in the air, can be imagined when it is realised that charcoal was the source of heating for tempering. From then until the early nineteenth century steel was a toilsome craft, demanding individual attention by craftsmen.

Usually these men worked in great secrecy, their ability to turn the usually brittle iron into a flexible metal capable of being sharpened to a high standard being ascribed to magical rites, the supernatural powers of the maker being transferred to the weapon. An early Briton with such a reputation was Weland the Smith, later a legendary figure of the Lambourne Downs of Wiltshire and maker of King Arthur's magic sword " Excalibur ".

Of a much later date is Andrea de Ferrara, a smith who learned his craft in Italy and then returned to practise it in the Highlands of Scotland. Before Andrea, no man in Britain knew how to temper a sword so that it would spring back if the tip were bent to touch the hilt. He is believed to have lived during the reigns of James IV and V of Scotland, and



60 Steel swords being ground in the Middle Ages.

so secret were his methods that he worked in a darkened cellar, though this practice very probably helped him to judge to a nicety the temperature of the blade he was tempering. However, it is easy to see how his mode of working aroused reports of necromancy and stories that Andrea's swords were perfected by the fires of Hell, brought to his workshop by his friend, the Devil.

Actually it is very unlikely that any of these men accidentally found out how to cast steel. The high temperature required was far beyond their capabilities, and their beautiful work emerged from long hours of patient, heavy labouring. To discover how the problem was overcome we must go to the city of steel—Sheffield. Sheffield's reputation as a steel-making centre goes back to mediæval times. In the thirteenth century the place had the reputation of making the best arrowheads, and the Earl of Richmond owed his success at the Battle of Bosworth at least in part to the fact that Sheffield supplied him with his arrow-tips. Chaucer's reference to the " Sheffield Thwytel " (eating knife) in his story of the Miller of *The Canterbury Tales* indicates that the town even then had a reputation for quality in cutlery.

By the beginning of the seventeenth century the industry had fallen on evil days, for in 1615 it was reported that 725 of the total of 2,207 householders in the town were dependent on the charity of their neighbours. Later there was a revival partly owing to the manufacture of clasp knives to a design introduced to Sheffield by Flemish workmen and also because the Sheffield smiths started to make their own steel.

It was still a laborious process. Iron bars were placed between layers of charcoal and kept in the furnace for as much as a week. This produced a metal called blistered steel, used for knives, razors, and swords. A further process necessitated heating this blistered steel in a wind furnace until the mass reached welding heat, when it was drawn out under a forge hammer.

These methods lasted until Benjamin Hunstman perfected a process of making cast steel. Hunstman's family was of German origin, living in Lincolnshire, where he was born in 1704. He was a quiet, thoughtful boy, preferring to study rather than play. In his late 'teens he moved to Doncaster and set up as a clock-maker and mender, adding to this occupation such diverse sidelines as lock-making and surgery. In the latter profession it was the perfection of his surgical instruments rather than his exceptional skill which pleased his patients. He was no charlatan, for he consistently refused to charge any fee for his operations.

His constant difficulty in obtaining the right kind of steel for watch and clock springs influenced him to study the manufacture of steel. The highest quality material he could obtain came from Germany, yet he had first-class surgical knives made in Sheffield. The result of his examination of the position was that he moved to Handsworth, near Sheffield, in 1740 and began experiments in great secrecy.

The following years were a story of disappointment and persistency which only he knew about ; for after his death the new occupants of his little forge found scores of pieces of metal buried deep in the earth of the surrounding garden. Subsequent analysis showed that the metal had been treated with various fluxes and heated to a wide range of temperatures, and all of them were failures. There is something very pathetic about the way this man worked on year after year on his own, achieving nothing but failure and creeping out into the garden at night to bury the evidence of his inability to make steel. Fortunately there was a happy ending to the story and a reward for his single-minded persistency. The process was costly and arduous, though the resultant steel was of a very high quality.

What Hunstman did was to arrange a dozen crucibles, each capable of holding about 34 lb. of metal, inside a furnace, which was then fired with coke. As soon as the crucibles were at white heat, he filled them with small pieces of bar iron, refilled the furnace with coke, and covered it. The heat thus produced was sufficient to melt the metal. The exact moment for " teeming " had to be judged by the colour of the molten metal.

All this trouble produced a steel of great hardness, and Hunstman realised that he had a substance of far wider use than merely for clock springs. He approached the Sheffield cutlers for contracts to supply them with his metal, but they rejected his offer. Hunstman then went over to Paris, where the French trade eagerly agreed to take all he could send them. Within a very short time knives and razors made in France from Hunstman's steel were competing successfully with Sheffield products even in the English market, and tardily the cutlers approached Parliament for legislation to prohibit export of the steel. When the Government discovered that the material came from Sheffield and the only reason it was not being used there was that the cutlers had themselves refused to buy it, the application was brusquely refused. Hunstman was soon very busy indeed, supplying both Sheffield and France. Inevitably, some of the cutlers attempted to wrest his secret from him. Hunstman had taken out no patent, and his sole protection was the secrecy which his workmen had sworn to observe. Most of the rumours stated erroneously that some sort of magic flux was used ; the least bizarre of these was that each crucible was topped up with broken glass. Some makers tried this without result.

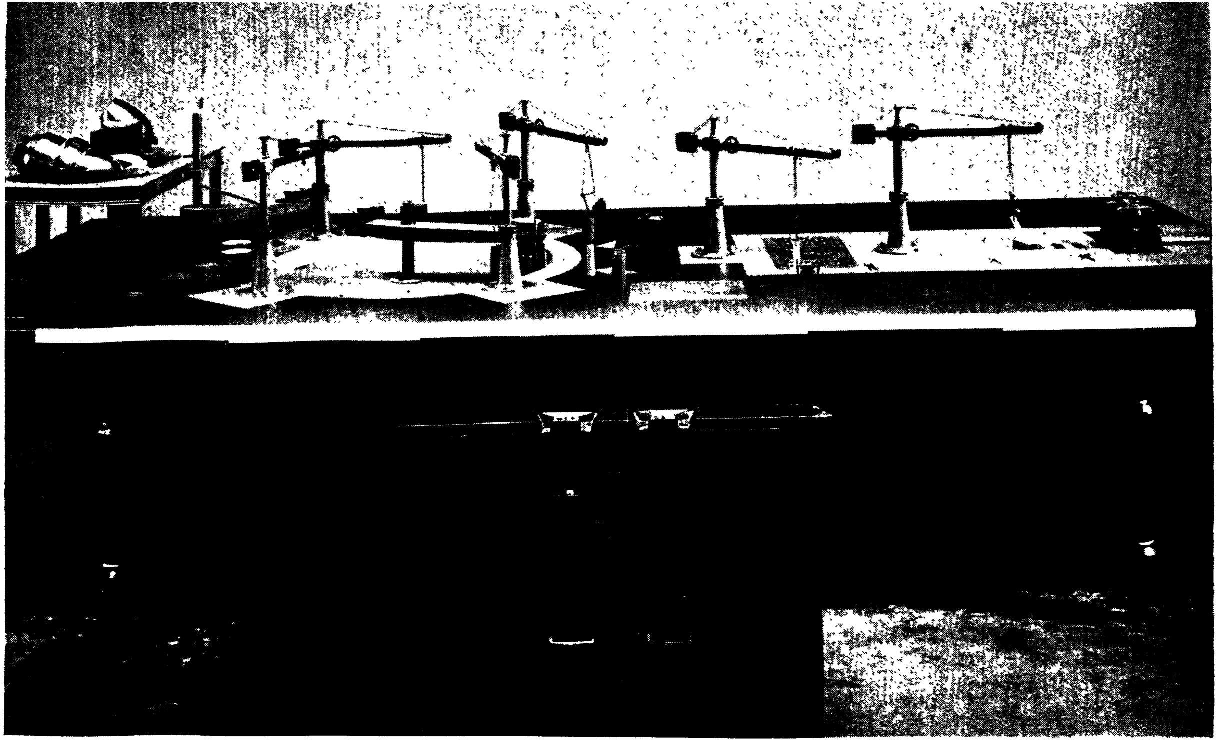
There is a story about a rival who got into the works by disguising himself as a cold and hungry tramp in need of the warmth which a seat close to the furnace could provide. The unsuspecting workmen, not to mention Hunstman, who supervised the process all the time, let him sit there for hour after hour watching every incident. This is probably as apocryphal as the similar stories told in other industries using new methods at the time, for Hunstman appears to have retained his monopoly for many years.

In 1770 he built larger works at Attercliffe, where he enjoyed six more years of prosperity before he died at the age of seventy-one. In his latter years his eccentricity and secretiveness became more pronounced, and he greeted most approaches with suspicion. Even when the Royal Society wished to enrol him as a member in recognition of the work he had done for science and industry, he rejected the offer.

His son carried on the business and Hunstman's steel became known and famous throughout the industrial world, people willingly paying a higher price for a tool for which it could be claimed that it was fashioned from Hunstman's steel. With this product Sheffield maintained its reputation, which it had been within an ace of losing through the short-sightedness of the cutlers who rejected the samples which the Quaker clockmaker brought them.

To-day some high-grade steel is still made in much the same way as that which Hunstman discovered, with electricity used as the heating medium instead of coke. The original method, though invaluable for production of tools and small implements, was clearly of little use to cater for the imminent Steel Age, where every form of transport from a bicycle to a liner, or a motor car to a railway locomotive, would need steel. The millions of tons for the framework of skyscrapers, the railway lines spanning the continents, and the machines of the mass-production factories demanded a different process, and it was not until eighty years after Hunstman died that the solution was found—first of all by Bessemer's blast furnace and a little later by the German system of the open-hearth furnace invented by Siemens.

The familiar story of the foreign refugee repaying his adopted country by bestowing on her priceless knowledge applies in the Bessemer family, whose son Henry did for steel as much as Cort did for iron. His father was a Frenchman, a skilled engineer who had amassed a comfortable fortune from his work both in his own country and in Holland. In middle age he



61 A model in the Science Museum, London, of a Bessemer steel works and soaking pits.

purchased a small estate near Paris and settled down to the life of a landed gentleman, being well liked by the villagers and the peasants of the district. When the French Revolution broke out his name was included in the list of enemies of the Republic, solely on account of his wealth, and he fled to England, where he settled down in Hertfordshire and started making medallions. By the time his son Henry was born in 1813, the business was quite a prosperous one, his products including medals for the victors over the country of his birth. As a child Henry played with castings and was allowed to make moulds himself. The twofold result was that by the time he reached his 'teens he was both an artist and an expert metallurgist.

At the age of twenty Bessemer went to London to work for himself, starting in the same line as his father. He also devised many inventions, one of the first of which was a machine for dating stamps on legal documents to prevent forgery. It was calculated that the device would save the country £100,000 a year, and he was promised a sinecure Government post as a reward. This did not mature, and Bessemer carried on with his metallurgical work. A gold or bronze powder for printers and painters which he produced at 14*s*. per pound instead of the prevailing figure of £5 10*s*. brought him an unexpectedly large income, and he was able to spend more time on research into steel production.

His problem was, in brief, the control of the amount of carbon in the iron. By driving streams of air into the furnace while the metal was still in a molten state he caused oxygen to combine with the carbon, increasing the heat of the furnace to a far higher figure than anything previously achieved. The changes which took place during the injection of the blast were rapid. At first the crude iron became ordinary steel of considerable hardness, then it changed to soft steel, and eventually to very soft iron. The gauging of the length of the process was a delicate matter, and when Bessemer first issued details of his method it failed in operation. When he perfected it, the iron- and steel-makers still remained unenthusiastic, with the result that Bessemer built steel mills of his own, which were soon supplying first-class material at £20 a ton lower than his closest rival. The Sheffield steelworks caused a complete change in the attitude of the industry, and the direct result of the general adoption of the Bessemer blast furnace system was to increase the production of steel in this country from 50,000 tons a year to 1½ millions.

Bessemer amassed a great fortune from his invention. He was knighted in 1879, seven years after his retirement from a life of vigour which would have doubtless made him famous in whatever walk he had chosen. He died in 1883, by which time he had seen the once slow process of steel production in tiny forges of his boyhood transformed into one of the greatest enterprises of man.

The Bessemer system was followed by the open-hearth method of William Siemens, a member of the family which founded the famous German engineering firm of Siemens and Halske. In this system hot air was directed into the furnace through a series of chambers, where it was heated to a very high temperature. In both systems iron ores which contained no phosphorus had to be used, and this factor severely restricted supplies. Two cousins solved this problem by lining the Bessemer converter with burned dolomite. They were Sidney Gilchrist Thomas, a London police court clerk who dabbled in chemistry as a hobby, and Percy Gilchrist, a professional chemist.

The new cheap steel was not of the high quality of the Sheffield tool and cutlery steel, and the search for improvement by addition of other elements now began. Robert Hadfield was one of the leaders in this research, and he produced manganese and silicon steels in 1882. Thus began a new era of co-operation between chemist and founder, and the development of special steel alloys is a story to which a new chapter is being added almost every month. Here the chemist in his laboratory is as important as the smith with his furnaces. This growth of the importance of applied research reaches into every industry to-day.

14

WEALTH FROM A TEST-TUBE

BEGINNINGS OF THE CHEMICAL INDUSTRY

THE real history of the industrial chemist does not begin until the eighteenth century, and even a hundred years later there was no chemical industry as we know it to-day. The progress of the chemist can be divided roughly into three phases. First comes the alchemist, who more or less secretly pursued his investigations, sometimes in the pursuit of knowledge and more often for the power and riches experiments might bring. In the second phase chemical experiment was thrust on industry through its need to perfect its inventions and to produce the goods of those inventions ; Watt had to become a metallurgist to make his steam engine work ; mine-owners needed to know about the properties of fire-damp in order to overcome the explosion danger. In the third phase the chemist became the inventor ; Macintosh investigated the properties of rubber and started a waterproof clothes industry ; Fox Talbot and Daguerre found chemicals to make photography possible ; Bessemer analysed the phenomena of heat and metal and made steel. Thus with the third phase science had advanced chemistry until it was a vital branch of existing industries and the creator of new ones. To-day, all modern industries are laboratory-born. The jet engine was principally a problem of metallurgy ; the plastics industry is solely a matter of test-tubes and retorts. Artificial fertilisers, nuclear fission, and medicines, are all in the hands of the chemist-inventor.

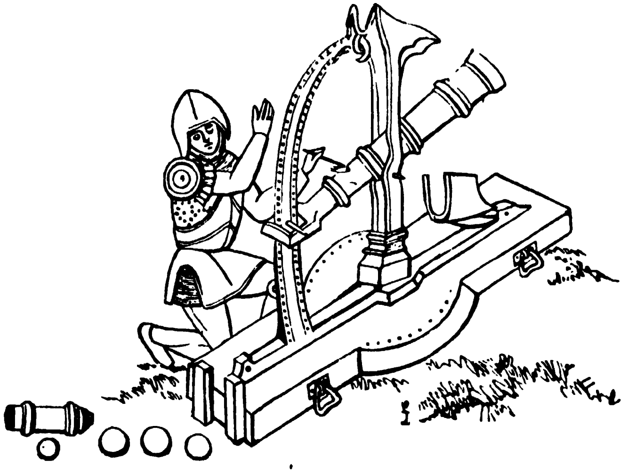
In every industry, either by private work or mutually sponsored research, the laboratory technician is the man who calls the tune. It is a pity that this recognition of the vitally responsible task of the chemist did not happen earlier. Time after time in this book it will be seen that the principle of an invention had been discovered and even tested years before. Nearly always the earlier failure occurred because of the lack of suitable materials with which to construct the machine. Equally we shall never know how many ideas discovered by persecuted and secretive alchemists were doomed to oblivion because of this failure to recognise the chemist's importance.

An outstanding personality in the ranks of the mediæval alchemists was Friar Bacon. One of the mental giants of English history, Roger Bacon shines like a brilliant star in the darkness of the England of the thirteenth century. In a period when the acquisition and practice of scientific knowledge was a business attended with considerable risks of religious persecution, Bacon travelled all over Europe, meeting charlatans and learned men alike, assimilating, probing, and investigating all the time. Only a man of his mental calibre would have attempted to set down the entire knowledge of mankind as known in his day, and it is a measure of his stature that he admitted that the task was too stupendous even though he attempted it. His contributions to knowledge were formidable. He showed that it should be possible to travel round the world, as Columbus was to prove later. He forecast the aeroplane and the power-driven boat, not as the prophecy of a seer, but as a scientific process capable of solution by the inventive genius of man. Two discoveries that he made apply to the survey of Britain's industrial growth—gunpowder and the microscope. Bacon's profound knowledge of the nature of things came partly from his own investigation and partly from his searches into the accounts, rumours, and beliefs of others, no matter of what age, race, or creed their protagonists might be. Few men before or since have been so ready to believe that knowledge knows no boundaries. It is therefore difficult to know which of the developments of science ascribed to Bacon were his own invention or merely a personal proof of what he had heard.

Gunpowder, of course, was known before Bacon made it. Coincidence or experiment—no one knows. It suffices to say that on the day this desperately poor man crystallised some salts and produced saltpetre, and then tried the effect of mixing sulphur and charcoal with it, the resulting explosion reverberated far beyond the confines of the miserable room in which the flash occurred. Chivalry and all that it meant in the shape of moated castles and knights in armour disappeared in the face of this tremendous power that Bacon unleashed. It was the English cannon which kept this country free from a conqueror's heel and allowed her little ships to spit destruction against massed power in the centuries which followed. The navies and armies of England were closely followed by her merchants. Roger Bacon's explosive paved the way for the development of the commercial wealth quite as much as it ensured military supremacy, just as his microscope drew back the curtain which hid Nature's greatest treasure chests. The reward for Bacon was to have his books denounced, while he himself was thrown into prison at the age of sixty-three. He remained in captivity for fifteen years, being released in 1292 and dying then at the age of seventy-eight.

Freedom from intolerance of religion was one of the means of bringing the chemist into the open. Gilbert, as we read in the story of electricity, was able to conduct his seemingly magical experiments in the Court of Elizabeth I with the encouragement of the Queen herself. This attitude paved the way for scientific investigators to find a special niche in English society; if their work and words were greeted with some disbelief, they were nevertheless tolerated and allowed to continue. The result was that the thoughts of succeeding generations of chemists were trained on lines of enquiry by evidence set down by these early pioneers. It was a useful start in a world-wide race.

An example of this preliminary is to be found in the life and work of Robert Hooke. A native of Freshwater, Isle of Wight, who was born in 1635, he was one of the earliest pioneers of the great synthetic thread industry of to-day. Hooke, the son of a priest, became a doctor and, more important, one of the great microscopists of his time. He built his microscope out of globules consisting of fused glass threads, and was appointed Curator of the Royal Society two years after that



62 The weapon which destroyed the value of armour : a powder-fired cannon.

body was founded. A remarkably ugly man, he impressed himself on the thought of the day by the sheer weight of his genius, for he certainly spent no time in ingratiating himself anywhere. Almost every night he spent in writing about the things he had seen with his microscope during the previous day, and his book published in 1664, *Micrographia*, included a report that cork was made up of tiny cells, an early hint on the basic construction of matter. Hooke seems to have realised that things are much as they seem if hidebound conventions of magical or divine influences are ignored. This resulted in a suggestion that as silk is merely exuded from a worm's body, it should be possible to make such a gum oneself and draw it out into thread. With profound truth, Hooke said that in his opinion such artificial silk would bring considerable profit to the manufacturer.

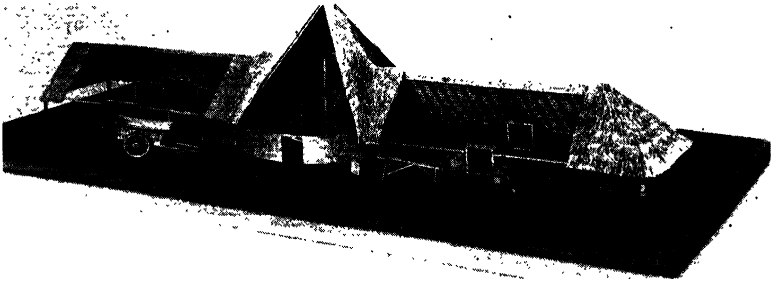
More than 200 years passed before a Frenchman, Chardonnet, obtained a patent for an artificial silk made from collodion, which unfortunately burst into flames very easily until the inventor arranged with Sir Joseph Swan, inventor of the electric filament lamp, to adapt the latter's process, and then the rayon thread industry was born. In this country the big name of artificial thread is Courtauld.

Courtauld is yet another instance of a refugee bringing untold wealth to the country of his adoption. Augustine

Courtauld, a French Huguenot, fled the country with his infant son concealed in a basket of vegetables. There is a story that, to avoid capture, basket and child were launched on a stream which carried them out to sea, where an English boat was waiting to pick them up. Nothing is known of the subsequent life in England of Augustine and his son, but it was the grandson of the child in the basket who founded the Courtauld business. His name was George Courtauld, born in 1761. He was apprenticed to a silk throwster in Spitalfields and then started his own silk factory at Pebmarsh, Essex. The business failed after two years. Shortly afterwards, Courtauld took a partner named Pitt and they started again, moving into a larger factory at Braintree in 1810. At this time, of course, they made natural silk material, but with the invention of artificial silk everything was staked on the new product. Huge sums were spent on experimenting, and even with a first-rate thread buyers refused to touch it, even though the artificial silk thread was offered free to manufacturers. But progress could not be held up—and the Courtauld enterprise grew apace to its gigantic size of to-day.

This brief account of artificial silk manufacture is an example of the slow evolution of the idea to commercial success in the early days of chemistry. It was largely due to the hidebound suspicion of alchemy which was a long time a-dying. One man who showed the important place of the chemist in the new industrial scene was Dr. John Roebuck, a man whose contributions to Scottish industrial growth deserved something more than the account of his life in the *Cyclopaedia of Biography*, published in Glasgow about a century ago. This simply stated: " Roebuck, John, a physician and experimental chemist, born at Sheffield, 1718, died, after ruining himself by his projects, in 1794." The ruinous projects included sponsoring James Watt's steam engine and prospecting for Lanarkshire's richest iron ore and coal deposits. Before then he made a fortune by chemistry.

Roebuck's father was a Sheffield cutler who had his son trained for a career in medicine, first as an assistant to a Northampton doctor and then as a student at Edinburgh University. He obtained his degree at Leyden University and



63 This model shows one of the last woad mills in the country, at Parson Drove, near Wisbech, Cambridgeshire, about 1900. Woad was a valuable vegetable dye before Perkin's discovery of aniline dyes.

returned to England to practise, settling in Birmingham in 1745.

Patients were scarce, and those that came received scant attention, for Dr. Roebuck spent most of his time in his laboratory. He improved refining of gold and silver and experimented with coal-fired iron-smelting furnaces. His main work was the investigation of improved methods in making acids for the Birmingham metal trades. With a partner named Garbett, he manufactured sulphuric acid by new methods (using lead tanks instead of small glass bowls), and it was so successful that he decided to erect a full-size plant in Scotland. It began operations at Prestonpans in 1749 and brought a handsome profit for the partners. Roebuck was a first-rate chemist ; he now fancied himself as an industrialist, and was not only ready but eager to launch into almost any kind of manufacture. When he could use his technical knowledge to improve quality and to simplify production, these enterprises were successful. Examples are the local pottery he started and, of course, the Carron Ironworks, Scotland's first, opened in 1760. Through Roebuck's careful analyses of raw materials and processing, Carron castings became the best in the country. Roebuck's subsequent activities with Watt belong to another section of this book, and though it is a chapter of failure in his life, it does not alter

Roebuck's place as one of our earliest and most resourceful inventor-chemists.

We now come to the first story of outstanding success and the undoubted creator of our chemical industry. A little more than a century ago, the City of London School became the first public school in England to teach experimental science. Among the first pupils was a boy named William Henry Perkin, son of a London building contractor. William's master, a man named Tom Hall, was so impressed with the boy's ability that he persuaded Perkin's father to let him take up a career in chemistry. Within a short time he was one of the laboratory assistants to Crookes, who later became Sir William Crookes, President of the Royal Society. Perkin worked on chemistry every waking hour. He fitted up a laboratory in his father's house and continued his research there after his working day was supposedly over. In his Easter holiday in 1856 he began the task of synthesising coal tar. This liquid, being produced in large quantities by coal-gas undertakings which did not know what to do with it, occupied the attention of many chemists at this time (an example of successful work with it is given in Chapter 12 on Macintosh's experiments).

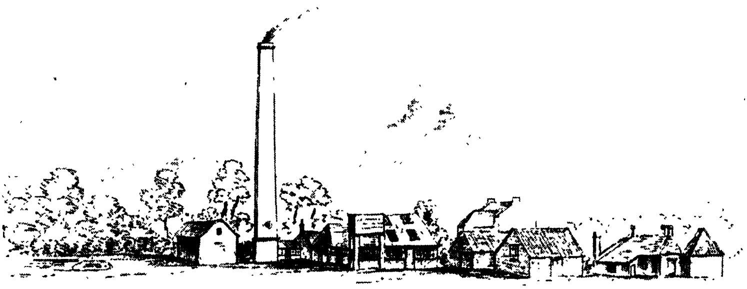
These chemists had obtained a slight hint of the varied substances contained in coal-tar, though they were certainly unaware that there were more than 200 of them. It was a brilliant German chemist, August Hofmann, invited to work in England by the Prince Consort, who set Perkin on his trail-blazing. He showed that naphthalene, one of the fluids obtained from coal-tar, could be converted into a crystalline alkaloid which was only slightly different from quinine. If quinine could be made in the laboratory, it would not only be a chemical triumph, but of enormous value to man.

As a matter of fact, Hofmann was in error in his premise, though the eighteen-year-old Perkin did not know this, nor would he have cared. He started experimenting in the production of synthetic quinine. He failed, of course, but one of his innumerable experiments yielded a blob of slime at the bottom of the test-tube. He might have washed it out and started on another line. Fortunately for the brightness of our homes and clothes to-day, he didn't. Instead he decided to see what this substance was, and as a preliminary he dissolved some of it in hot water. The test tube shimmered with a liquid of brilliant purple. Perkin had produced the first coal-tar dye, the forerunner of the aniline dyes which compete with the brilliance of the rainbow.

He dipped bits of silk in his dye and hung them up in the sun for days on end. He dried them and then boiled them. The colours did not move ; the brilliance was unimpaired. Perkin dyed some strips of silk and posted them to Mr. John Pullar at Perth. He chose this dyeing expert because there was no person who knew so much about the commercial exploitation of dyes. John Pullar was the son of a prosperous cloth manufacturer in Perth. He went to London in 1821 to study dyeing methods, and then he returned to set up in business on his own—in rooms in Burt's Close, his staff consisting of an assistant and an apprentice. This was in 1824, when John Pullar was twenty-one years old. By dyeing better and in a greater variety of colours than anyone else in Scotland, he quickly built up a large business until his dye-works were the largest in the country.

A month passed before Perkin heard the expert verdict of Pullar : " If your discovery does not make the goods too expensive, it is decidedly one of the most valuable that has come out in a very long time." So the letter from Perth, dated

64 Perkin's own sketch of his first dye works as they appeared in 1858.



12 June 1856, began, and it continued by saying that purple had never been dyed fast on silk and not very satisfactorily on cotton.

Perkin's discovery was still in the test-tube stage, but during the summer he began small-scale production, aided by his brother. A patent was secured in August 1856, and then Perkin went to Perth to begin work on a practical scale. Unfortunately, it was patchy, and lack of a suitable fixing agent made the colour merely a pale violet. The enthusiasm and encouragement of Pullar kept Perkin trying, and the result of their mutual effort was the use of tannin as a fixing agent. But the dye was still far from reliable, and with an introduction from Pullar to a Scotsman in London who was an expert on dyes, a man named Thomas Keith, Perkin went home.

He evidently did not regard the setback as of any great importance, for he threw up his job at the Royal College of Chemistry and, with his father and brother, set up in the dyeing business. Their little factory was built at Greenford Green, not far from the present Northolt Airport. The troubles which the Perkin family experienced in the first aniline dye plant in the world are too numerous to be told here. The benzol supplied from the waste of gas plants had to be redistilled to get rid of the unwanted ingredients, and Perkin had to juggle with mixtures of benzol and nitric acid which could have given the quiet little Middlesex village the mightiest explosion it had ever heard. There were many minor explosions during this period, fortunately without seriously injuring any of the workers. Eventually the day came when there were several pounds of black powder, and Perkin started to visit the dyers and calico printers of the country, usually having to do some sample dyeing himself to show the doubting experts how a synthetic dye worked. He received indirect help from France. By an error, the French translation of his process used for a patent in that country was invalid. Many French chemists began the production of aniline dyes. Soon dresses and material were arriving in Britain in the new French colour called mauve. Women, then as now, demanded the French fashions, and the British textile and cotton manufacturers were compelled to adopt the dye they had rejected earlier. The eighteen-sixties were Perkin's decade. Queen Victoria, in half mourning for the Prince Consort, wore a mauve dress at the South Kensington International Exhibition of 1862 ; all the women of London's society did the same. Postage stamps were printed in lilac, and furnishings appeared in an imposing purple. Perkin also created many other synthetic dyes, notably an improved magenta.

When Perkin had started his experiments there were only three reliable dyes which were reasonably impervious to fading : red, blue, black. Perkin unlocked a rainbow box in his laboratory—and incidentally withdrew the first of the innumerable priceless substances which are hidden in the black, noisome, and sticky gasworks " waste "—coal-tar. He found aniline purple, the first of the 3,000 commercially-made products of to-day, ranging from the sulfa drugs to aspirin, and covering scents, flavourings, colours, and explosives in between. In 1873 he sold his business, and at thirty-five returned to pure research with a fortune of £100,000. Among his successes in this period were the synthesis of coumarin, the first synthetic perfume derived from coal-tar, and the beginning of the artificial perfume and flavouring industry.

Perkin was knighted in 1906, the jubilee year of his discovery of mauve, and he died in 1907, by which time Germany had started to gain a virtual predominance in the manufacture of synthetic dyes—a situation which brought a bitter lesson for British industry when war broke out in 1914. Fortunately, the lesson was learned, and we regained our rightful place in the business.

In vivid contrast to the happy story of Perkin's personal success is another and contemporary one. Someone one day will write a drama based on the life of Archibald Couper. His story has the ingredients of high tragedy. Couper solved the mystery of the structure of organic compounds—the key to the vast modern chemical industries producing plastics and fibres like rayon and nylon and so on—before 1858. It was not even realised until 1885 that Couper had done so ; it was not advertised until 1906, and not formally commemorated until 1931.

Couper was born in 1831, the son of a cotton-mill-owner at Kirkintilloch. About 1850 he went to Berlin, returning to Scotland in 1852. By 1854 he was back in Europe, studying chemistry in Germany and France. In Paris he wrote his momentous paper on the quadrivalence of carbon (the power of a carbon atom to link up to four other atoms), for submission to the French Academy, and submitted it to his teacher, who regarded the views as so revolutionary that he sought further advice. This delay robbed Couper of priority, for August Kerkule, later one of Germany's greatest chemists, who had also been investigating on the same lines, startled the scientific world by publication of his findings.

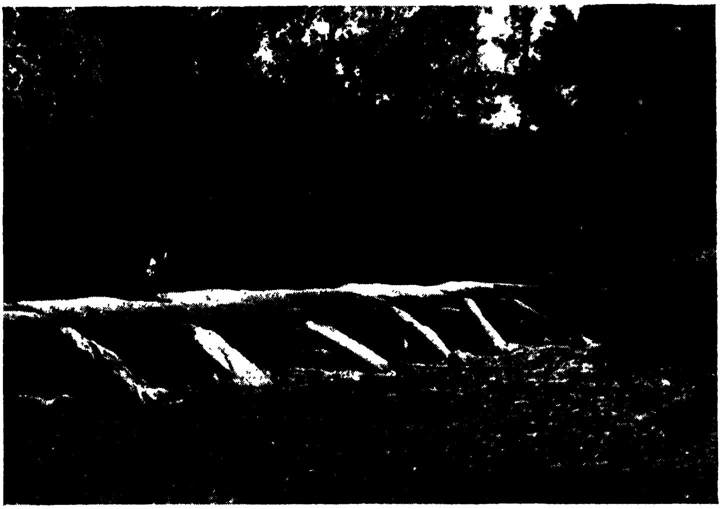
Despite this, Couper's work appeared in a scientific journal and was ascribed to "Archibald Couper Esq.", the only clue to the author, his reputation, or his work.

It was only when a German chemist named Richard Anschutz started to write a biography of Kerkule in 1885 that this work by Couper was noted. The biographer later began a long search for facts. In 1903 he obtained a few vague clues. Edinburgh University's registers gave little beyond the dates of Couper's membership of the University as a student under Dr. (later Lord) Playfair. The few men still alive who had been in the scientific circles of Edinburgh, Paris, and Berlin in the 'fifties searched their memories for details of the " tall young man of distinguished aristocratic appearance ", as one of them described him. So the tragedy was revealed. Either because of his bitter disappointment at the fame which had been snatched from him or, as others believed, through an attack of sunstroke, Couper went insane. He was admitted to an institution in July 1859, and finally discharged in November 1862 into the care of his mother until his death in 1892. For thirty years he ambled about Kirkintilloch in the care of an attendant, the townsfolk never realising that the pathetic figure was the man who, at twenty-seven, had made scientific history. Not until 1931 was a plaque placed on his home, to mark the centenary of his birth, an indirect memorial also to the German chemist who had spent years in finding out the facts about a genius who might otherwise have passed into complete oblivion.

Couper's discovery was made in 1858. Eight years later another young man furthered the progress of chemistry by showing the relationship between atomic weights of different elements. He achieved little more recognition than Couper, but he was more philosophical about it, and threw up all research work to become an industrial chemist in a sugar refinery.

John Newland was born in South London in 1837 of Scottish-Italian parents. He studied chemistry at the Royal College, and in 1860 he abruptly left to fight in Italy in Garibaldi's forces of freedom. In 1866 he presented his paper to the Chemical Society, and (partly because some elements were unknown at that time and this jeopardised Newland's theory) his audience, smiling politely, ignored the whole thing. Some twenty years later, fortunately well before his death, he was awarded the Davy Medal for his discovery.

The discovery of coal-tar dyes opened the door to the manufacture of more elaborate organic chemicals. Disinfectants, fertilisers, and medicinal drugs began to appear, instead of chemicals intended almost entirely for the textile and metal trades. Side by side with this probing into the structure of matter, the slower road to control of the power of the atom was followed, culminating in the success of atomic fission before the war. There can be no doubt that Britain's laboratories were very early in the opening up of industrial processes of these new sources of material and power, and equally that private enterprise and Government were slow to exploit them. The nineteenth century was a comfortable period for industry ; there was much to make with existing materials, and the restless spirit of the early years of the Industrial Revolution was lost. It took two wars really to shake us out of our lethargy. When the reaction came it was profound, and the new triumphs of chemical research in Britain promise to be greater than the old.



65 A Bronze Age bridge : Tarr Steps, Somerset.

66 This Roman road, Richnild Street in Gloucestershire, has been in constant use fo 2,000 years.

III

TRANSPORT

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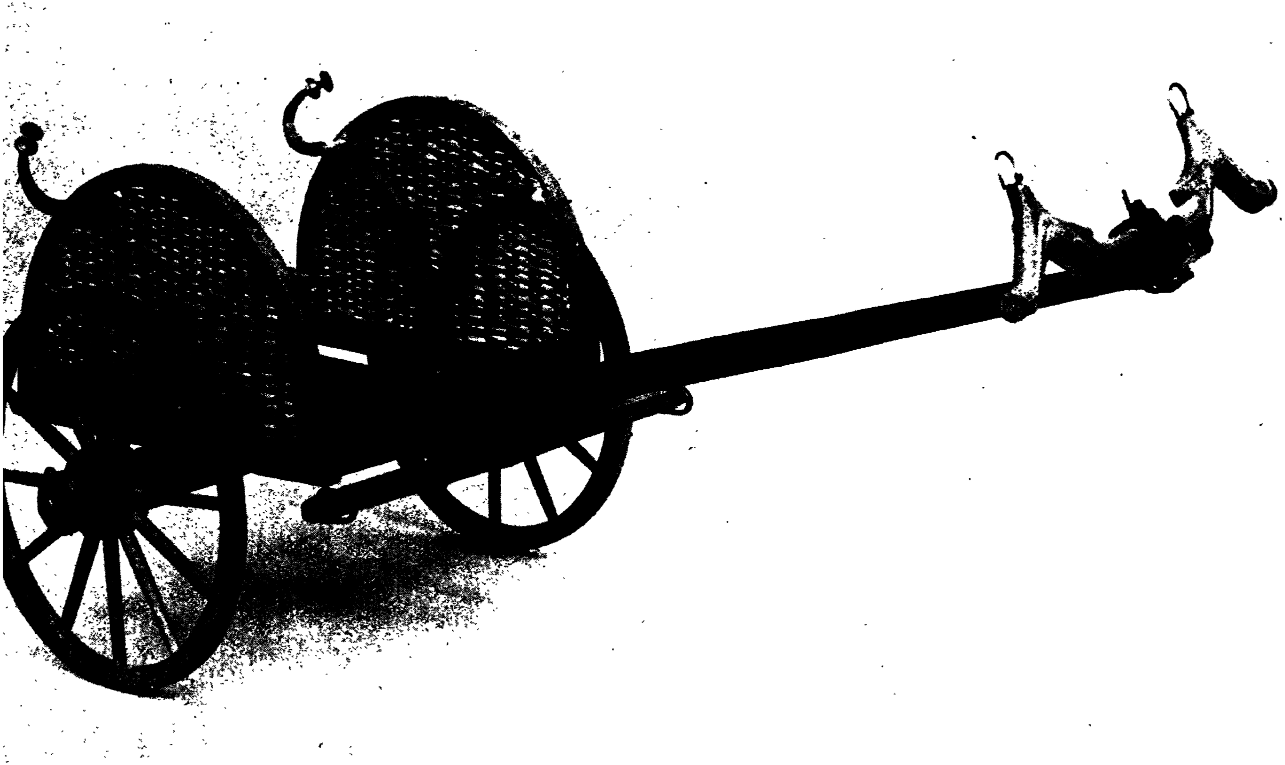


67 Reconstruction of an Iron Age chariot.

15

THE QUEEN'S HIGHWAY

BRITAIN'S ROADMAKERS AND THEIR ROADS

THE men who made the first roads in Britain were at work some 14,000 years ago. There may indeed have been a single prehistoric genius who was responsible for the general scheme. At any rate, there was a coherent plan of road-making; the ancient tracks did not just happen. Undoubtedly this first road-maker was a priest, and his knowledge of surveying and astronomy surrounded him with an aura of supernatural ability. From skyline to skyline across the hills of Southern England he placed his marking stones, and these gained such magical significance that each area became holy ground. To be buried at such a place was indeed an honour, and so to-day the long barrows of the New Stone Age will be found to be in alignment, one being a landmark from the other. Centuries later crosses were erected in the same way, and afterwards the churches were built on the sites. A famous example is Cirencester church, which is a focal point for the Gloucester road and also for the Fosse Way, both of prehistoric origin.

Neolithic man did not have to worry greatly about attacks by other tribes. He feared most of all the forest and the marsh : the one because of its wild animals and the danger of getting lost among the trees and the other because the sticky clay made movement difficult or even impossible for the greater part of the year ; and it meant the obstacle of a river. Accordingly he kept to the hills, and so his tracks converged on the junction of the watersheds of Southern and Midland England, Salisbury Plain. Here, at Stonehenge, Woodhenge, and Silbury, were large communities which in their way rivalled the glories of the primitive civilisations of the Middle East. The man-power required to construct an immense earth mound like Silbury or to carry out the building of Stonehenge (how it was done is still a matter of conjecture) indicates that the surplus wealth to feed the builders far exceeded that which could be derived from agriculture or hunting. It came from trade—along the roads of prehistoric Britain.

One of these great trading routes which can still be traced over long stretches is the trackway running from Cornwall to Salisbury Plain and thence in two branches, one to a prehistoric port near Colchester and another to Dover. Along this highway went ingots of tin and also gold from Cornwall and Wales. It is even suggested that by the time of the Iron Age (*circa* 500 B.C.) the metal was being carried in wagons, a development which was far ahead of the traders from Europe who took the metal, for they had to use pack-horses. One ingot due for shipment to France fell into the water in Falmouth Harbour and was found thousands of years later. It weighed about 130 lb. and was concave-shaped so as to fit closely on the back of a horse.

Herds of cattle were also driven along these roads. Camps, well fortified so that the animals would be safe from the attacks of wolves, existed at intervals of a dozen miles.

Thus the British tradition of the road as a vital factor in a trading economy was instilled long before the Romans came. We are inclined to consider our heritage of highways as the work of Romans. In fact, the road system was already well developed when Julius Caesar's legions landed. His first invasion was a fiasco, principally because the tribes were able to converge quickly in the attack area in Kent. There seems to be no doubt that chariots were used by the Britons in large numbers, and it would have been quite impossible for these to answer the alarm without fairly good tracks. The communication system built for trading purposes served the country well—the Romans were kept out for nearly a century. When full conquest began in A.D. 43, large-scale landings were made at Dover, Richborough, and Lympne, and the Romans drove along the roads to Canterbury, then crossed the Thames to Colchester. Three years later they were the masters of the

68 This trackway near Cholesbury, Buckinghamshire, is of prehistoric origin.

69 " The Roman Steps " in the Rhinog Mountains, Merionethshire. The track was probably used even before Caesar's invasion as a trade route for mineral porterage.

country up to the Fosse Way, which ran from Lincoln, through Leicester, Cirencester, and Axminster, to the Channel coast. This was a prehistoric way along which jet from Yorkshire and lead from the Matlock area had been carried for centuries.

The Romans adopted and adapted the ancient British roads. They were good engineers who recognised the quality of the tracks established centuries before they arrived. Their innovations were made because the centre of trade was moved from Salisbury Plain to London, and this necessitated the construction of Watling Street and what is now the Great North Road. Roman roads were not built as straight as is popularly suggested. It is true that improved surveying increased the point-to-point marks of the Neolithic builders from ten to twenty miles, and this eradicated some curves, but the idea that a mania for straightness for speed and safety against ambush caused the Romans engineers to drive through forest and marsh or up and down steep hills irrespective of obstacles is quite wrong. Nevertheless, the roads curved back to their original course as soon as it was possible. The Fosse Way, for example, which had previously wandered along the highest ground, was straightened so that it was never more than six miles off a straight line on its 180-mile route between Lincoln and Axminster.

The Romans gave this country a heritage of well-constructed roads by which London was connected with Dover, Colchester, Norwich, Lincoln, Doncaster, York, Carlisle, Lancaster, Chester, Leicester, Worcester, Gloucester, Bath, Exeter, Dorchester, Winchester, and Southampton. The list of towns reads like the destinations of main-line expresses in the twentieth century or the names on the signposts of our arterial roads; and well it should, for the road- and rail-builders could do little but follow the system perfected before A.D. 400.

When the Romans came the roads were mere tracks, relying on the hardness of the high ground to maintain the surface. Mostly they ran on chalk or gravel and stood up well to the traffic of 1,000 years or more, though some gradually sank deeper and deeper through the pounding of hooves and the crushing of the wooden wheels. A section of prehistoric road crossing the limestone of Willersey Hill, near Broadway, is in a 10-foot channel, and it is estimated that, at the rate of 2 inches of wear every 100 years, this road must have been in use for 6,000 years, and it was not used to any extent after the beginning of the Christian era.

The Romans made roads which were more durable than this hard, natural ground. With almost unlimited supplies of slave labour, they raised the track well above the level of the surrounding country. The best roads were about 15 feet wide, sufficient to accommodate two columns of troops marching in their usual rows of six passing one another and to allow two heavy carts with their standard track of 4 feet 8 inches (it is noteworthy that the modern railway track is 4 feet 8½ inches) to pass easily. The foundation was of large stones carefully fitted together; next came a layer of smaller stones called the *rudus*; the third layer, the *nucleus*, was of any available broken material bound together with lime mortar, and finally came a cambered *dorsum*, which was of stone slabs or rammed material cemented together. This system was varied greatly according to the terrain. On a hard surface the *dorsum* might be placed straight on the ground; on marshy land, bundles of sticks were thrown down first or a causeway of heavy timbers built into a kind of bridge.

Built primarily for strategic use, the Roman roads became great industrial arteries, taking iron from the Forest of Dean, lead from Derbyshire, tin from Cornwall, and gold from North Wales. After the Romans left the country in the fifth century, the roads continued to be the principal means of communication. The Anglo-Saxon traders in skins and woven fabrics, wine and oil, precious metals and useful metals moved along them. It is probable that some attempt was made to keep the roads in repair. Six centuries after the last Roman road surveyors left the country, Harold marched his army from Stamford Bridge on Ermine Street near York to London in order to try to repel the Normans at Hastings. He covered the distance at a rate of more than forty-five miles a day—a testimony not only to his troops, but to the good surface of the road along which they marched.

But neglect began soon after this. The Romans' work might have endured except for the deliberate destruction by farmers, who stole the stones for use in their barns and yards. Carts began to make wide loops round these bad patches; as they turned the ground into a morass, other drivers went still further round, until the original straight road became a sinuous track as much as 100 yards wide. In 1285 Edward I ordered that all undergrowth and ditches should be done away with for 200 feet on each side of the road, so that robbers could not conceal themselves. Henry VIII further aggravated the situation by passing a law which allowed travellers to drive or ride by the side of impassable roads even if it meant spoiling growing crops. This King also unwittingly endangered both roads and bridges by the dissolution of the monasteries. The construction of a bridge was regarded as a pious act which would bring its own reward in after-life, and many monasteries also devoted much energy to keeping the roads in good condition, particularly if they were used by pilgrims or were of value to the farms under the monastery's control.

Yet it was just at this time that industry began to need good roads. Towns were trading with areas far beyond that of the nearby villages. More than 70,000 people in London were busily turning the city into the principal trading centre of England—and of the world. Pack-horses, which had been sufficient to carry the goods of the previous centuries, were inadequate. Huge wagons were lumbering along the roads to and from London, their dozen horses or oxen straining to pull the bales of wool and woven cloth from every corner of England. In a matter of years the roads were churned into foot-deep ruts by wagon wheels, and seas of mud made horseback riding an ordeal faced only by brave men. The famous Highways Act of 1555 was then passed to make every citizen responsible for the upkeep of the roads. In each parish every adult person was supposed to work for six days a year under the control of an unpaid surveyor appointed by the local justices of the peace. In practice the law was not observed. The surveyor usually knew nothing about road-making, and if he was at all conscientious he became the most unpopular man in the district. The six days of work was carried out by substitutes, usually the village idiot or the oldest inhabitants, who poked about with a spade when they were not leaning on it and enjoying the sunshine. Local farmers would send their men for the six days' work when the weather was so bad that work in the fields was impossible ; the unfortunates crouched in the bushes until it was time to go home.

Things went from bad to worse, and the easy path of restricting traffic which has appealed to worried and incompetent legislators until the present time produced innumerable laws from the beginning of the seventeenth century. Four-wheeled wagons or loads of more than 1 ton were prohibited in 1621, and a little later the maximum number of horses hauling a vehicle was restricted to five. Still the ruts grew deeper, and someone had the fatuous idea of widening the wheel rims to spread the weight. Accordingly in 1751 the majority of carts were compelled to have tyres more than 9 inches in width, and one enterprising cart-maker built a wagon which ran on rollers. The Government decided to

70 General George Wade, builder of strategic roads in the Scottish Highlands.

encourage this plan and allowed all such vehicles to pass toll-free. The strain on the limited team of horses may be imagined, and the cart-builders obeyed the letter of the law and evaded its spirit by making their enormous rims slightly bevelled so that only the centre touched the road.

The first glimpse of the revival of a decent road system had come in 1663, when the Turnpike Act was passed. This permitted tolls to be charged on a section of the Great North Road, and in the next century turnpikes increased rapidly in number. They were heartily disliked by the local inhabitants, but they were an inestimable boon to the carriers moving from one end of the country to the other. Even though the merchants paid tolls at frequent intervals, the improved surface of the turnpikes represented a saving in time and horseflesh, not to mention the carts. The contrast between the turnpike and the decaying free road encouraged the toll payment idea, especially as in theory it was profitable. By the beginning of the nineteenth century 23,000 miles of roads were in the hands of the trusts. Some of the 1,000 organisations concerned merely took the revenues and ignored the roads, but the majority at least made some gesture towards giving a return for their money. The first great road-builder of this renaissance was a soldier, and his work was primarily carried out for military reasons. He was General George Wade, and he was given the job of constructing roads in the Highlands after the Jacobite rising of 1715. The whole scheme, which was started in 1726, was carried out by soldiers, and they built some 250 miles of roads in a country where they had been completely non-existent. Wade had unlimited supplies of stone materials at his disposal, but the mountainous terrain made his network of roads the major civil engineering job of his generation.

In England a little later, a remarkable character became a famous road-maker. He was Jack Metcalf of Knaresborough, known over a wide area as Blind Jack. He caught smallpox at the age of six and was left totally blind. Nevertheless, he lived a perfectly normal life, walking and riding by himself wherever he wished to go. No one knew better than he of the sudden pitfalls and the dangerous morasses of the roads. He once tramped from London to Harrogate, making mental notes of the varying state of the road the whole way. In 1765 he heard that a road was to be built from Harrogate to Boroughbridge. He had hunted and rambled over every foot of the route and knew the ground as well as he knew his own Knaresborough. He applied for a contract to carry out the job, and was awarded one for a three-mile stretch. He built a good foundation of broken stones whose sharp edges prevented them from being moved by the pressure of traffic, as was the case with the rounded pebbles normally used, and his road proved perfectly satisfactory. The result was that he obtained contracts to build many more roads in Yorkshire, and altogether he built nearly

200 miles of them, making embankments or cutting through small hills to keep his routes straight and reasonably level.

Metcalf was one of those blind people who so developed his other senses that in many ways he was better equipped than those with sight. In some inexplicable way he could sense the type of sub-soil through his feet, shod with heavy boots though they were. For example, during the construction of the road between Harrogate and Knaresborough he was walking through a field when he suddenly stopped and ordered his workmen to start digging. Some feet down they unearthed an ancient causeway which provided large quantities of stone for his road.

Such was his ability to feel his way that he regularly acted as a guide for travellers wishing to walk across the moors, and in winter-time or when mists lay heavily over the area he had more commissions of this kind than he could take. He lived a very full life indeed. Apart from running the first stage wagon between York and Knaresborough, he was also a fish-dealer, coal-merchant, and musician. At the time of the '45 Rebellion he joined the Army. It is noteworthy that he obtained his road contracts, not because people were sorry for him, but because he knew the territory far better than anyone else. It brought him a considerable fortune of £65,000 on which he retired with his wife and large family to Spofforth, where he died in 1810 at the age of ninety-three.

Metcalf was the real pioneer of modern road-building in England. He was followed by Thomas Telford, born in a shepherd's cottage in Dumfriesshire. His father died while he was a baby, and he was brought up in extreme poverty by his mother, who eked out a living by occasional farm-work. Despite his hard life he was an ebullient lad, being known as "Laughing Tam". In between jobs for any farmer who would give him a few coppers and a meal, he attended the parish school, and at fifteen he was apprenticed to a stonemason. At one place where he went to fix some stonework his interest in literature impressed the woman of the house and she let him have the free run of the library. The result was that he taught himself to read in Latin, French, and

German, and he became something of a poet, a few of his verses being accepted by a magazine when he was twenty-two. He did not, however, allow this minor literary triumph to go to his head, and he continued to work as a mason. His skill spread his reputation far and wide, particularly as regards the construction of bridges and canals.

In 1802 he was asked to examine the best way of improving the economic conditions of the North of Scotland, where many of the inhabitants were living in terrible conditions of privation. He reported that an outlet for the tweed manufactures of the crofters and an expansion of the fishing industry would help to alleviate distress, particularly if roads and canals opened up communication with the South. The Caledonian Canal was one of his works which did not at first succeed, but his roads proved an immediate benefit, and " advanced trade in the Highlands ", as it was said at the time, " by at least a century ".

In eighteen years Telford built 920 miles of new roads and 120 new bridges, besides repairing and improving hundreds of others. Some of his work was on the Wade roads, which had by then decayed, not through traffic, but because of the climatic conditions of the Highlands. He used strong foundations of large stones to provide good drainage, and covered them with broken fragments and then even smaller stones as a top layer.

Telford gained the reputation of being the best road-builder in the country, which resulted in the Postmaster-General, who was responsible for seeing that his mail coaches reached their destinations in the shortest possible time, commissioning him to survey the London–Holyhead road, the main artery connecting London and Ireland. Twenty-three turnpike trusts maintained the English sections of the road in varying conditions. At Conway the surface was so bad that it was normal to take coaches to pieces and carry them by pack-horse as far as Holyhead. It took Telford five years to complete his survey. He was given the contract. On some sections he built entirely new routes, leaving the old Watling Street at Wroxeter, and driving straight through to Shrewsbury, Llangollen, and

Bangor, thus reducing the 280-mile road by twenty miles. Telford also built the famous bridge across the Menai Straits. This masterly piece of engineering, 1,000 feet long, was opened in 1826. Five years more passed before the whole route was complete, the road work costing a little more than £600,000, and giving a 30-feet-wide carriageway with a central section of heavier construction of 18 feet. When Telford began his survey the fastest mail coaches were taking thirty-eight hours for the journey ; after the road and bridge were opened for traffic, the time dropped to twenty-nine and a half hours.

Telford later remade the Glasgow–Carlisle road, and in 1824 began a survey of the Great North Road. This again took five years, and when his scheme was placed before the authorities the Railway Age had dawned. His plans were therefore not adopted before he died in 1834.

Telford had a rival (a friendly one, for the men knew each other well) in John McAdam. The man who gave his name to a type of road surface was born at Ayr in 1756. The family name had been McGregor, but when the clan was outlawed the name was changed. His father was in comfortable circumstances, the founder of the first bank in Ayr. When John was fifteen he was sent to the care of an uncle in New York because of the sudden death of his father. Here he became a successful merchant, and he returned in 1783 to his homeland with sufficient money to maintain the family estate. He was also a magistrate and got himself appointed trustee of the local roads. He remained in the district for some fifteen years, and took a personal interest in the road improvements. In 1798 he accepted a naval appointment at Falmouth (the terminus of the packet boats to the New World and an important naval base), where he continued his investigations into road maintenance and made his first important experiments in building roads by which the traffic itself consolidated the stones into a firm surface. At the end of the Napoleonic Wars he was appointed surveyor to the Bristol Turnpike Trust, and in two years he had put 150 miles of highway into first-class condition. Other turnpikes asked for his advice and help, and by 1819 he was surveyor to thirty-four of them. His work occasioned endless travel, and he estimated that he covered 30,000 miles, spending £5,000 out of his pocket in doing so.

The great advantage of McAdam's roads was that they were cheap. He required no heavy foundation, but laid his stones directly on the subsoil, maintaining that in this way he obtained a cushion which prevented the stones being pounded to pieces. The size and type of stone used in his 10 inches of material were the whole secret. He regarded it important that no stone should be more than 1 inch across. His foremen were given small balances to make periodical checks that no stone weighed more than 6 oz. The stones he used were mostly limestone or sandstone, which slowly ground away to fill every crack and cranny with fine powder. This, except in very dry weather, acted as a cement.

McAdam's roads were carefully cambered, with the result that, after a little wear, there was an almost waterproof material which threw all moisture to each side of the road. The success of the system was such that in 1826 he was appointed Surveyor-General of the Metropolitan Turnpike Roads and he was able to put the entire main road system on a basis not known since the Romans evacuated the country.

Then within five years, the roads fell into disuse. The arteries which had carried the stage coaches, the long lines of pack-horses, and the groaning horse-wagons were deserted by all but local traffic as the railways multiplied in every direction.

It is true that between 1827 and 1840 there were signs that steam carriages would compete with the railway locomotives. A steam coach service, carrying fifty passengers, ran between London, Birmingham, and Bristol in 1838, and there were several steam buses, notably those of Gurney, James, and Hancock from 1822 onwards, but in the fifth decade of the century they were killed by repressive legislation in favour of the railways.

About the only machine which could safely be used on the roads was the pedal-operated bicycle, invented by Kirkpatrick MacMillan, a native of Courthill, Dumfriesshire, in 1839. Incidentally, MacMillan also has the record of being the first

71 A highway for the Motor Age: the dual carriageway of the Winchester by-pass from London to the South-West.

cyclist to be prosecuted for riding to the common danger when he knocked over a child in the Gorbals district of Glasgow in 1842 at the finish of a forty-mile ride.

But cycles, however popular for recreation or personal travel, could contribute little to industrial transport. Even when the roads were silent and the steam was hissing from the busy railway locomotives carrying the nation's enormous output of goods, the engine which would make those roads busier than ever before was regarded as a practical proposition by engineers.

The American inventor Edison once said to British friends : " The motor car ought to have been British. You first invented it in the 1830's. You have roads only second to those of France, and you have hundreds of thousands of skilful mechanics, but you have lost your trade by the same kind of stupid legislation and prejudices that have put you back in many departments of the electrical field."

The " stupid legislation " was the notorious Locomotive Act of 1865, which required that one of the minimum crew of three of the mechanically propelled vehicle should walk at least 20 yards ahead with a red flag, while the vehicle itself was limited to a speed of four miles per hour. This law was not repealed until November 1896—two years after the first car had been imported. The driver of this automobile brought Scotland Yard's forces out at the double in 1895 when he dared to drive in London, and he was warned not to do it again, and even in the few days before the repeal a summons was applied for against the driver of a car in the Lord Mayor's Show who had omitted to engage a man with a red flag, the various banners which preceded him for half a mile up the procession not being considered a valid warning.

What this diehard obstinacy cost Britain, then at the very peak of her industrial and inventive powers, can only be conjectured. The metallurgists, tyre-makers, and engineers were available if there had seemed the slightest chance of putting mechanical vehicles on the roads without thereby committing misdemeanour. There was no such chance, and so Dr. Otto, aided by Gottlieb Daimler, who had worked in a British engineering firm, produced the first gas engine in Germany in 1875. Ten years later Daimler made a faster and lighter engine and the motor car, or, rather, the motor bicycle, was born.

France did most to exploit the invention. Cars were being improved under the impetus of motor-racing with non-stop trips between Paris and Bordeaux at fifteen miles an hour while Britain had still not seen a single car on her roads, and had yet to make her first model (a Lanchester) in 1896. It took the genius of the Hon. Charles F. Rolls and F. H. Royce, of " Pa " Austin and William Morris, to gain a place for British cars, and make up the leeway which penal legislation, and later free imports, caused.

Over and over again legislation has impeded the progress of our automobile industry. In 1910 taxes imposed a burden on large cars, and this forced manufacturers, notably Singer, Morris, and Humber, to turn to light vehicles. While the machines were the finest in the world of this class, they did not appeal to overseas markets, where the more powerful Ford easily held the field. Nevertheless, Britain continued to make very good heavier cars, and the first car to cover 100 miles in an hour was a Talbot in 1913.

Never have we been able to use the public highway to the best advantage since the restrictive laws of the Tudors. The long story is a sorry one, lightened only by the ingenuity and resource of men who have tried to improve the roads and the vehicles which use them. No trader has been so thwarted as the motor manufacturer, and his emergence as one of our greatest sources of wealth, with 800,000 vehicles a year being exported, is a veritable triumph.

But passenger and goods traffic is still penalised. There are 180,000 miles of roads in Britain, good as regards quantity, but poor in suitability. Perhaps the motorways which are planned will finally ensure that our road transport can really move as invention says it should instead of the law saying that it must not.

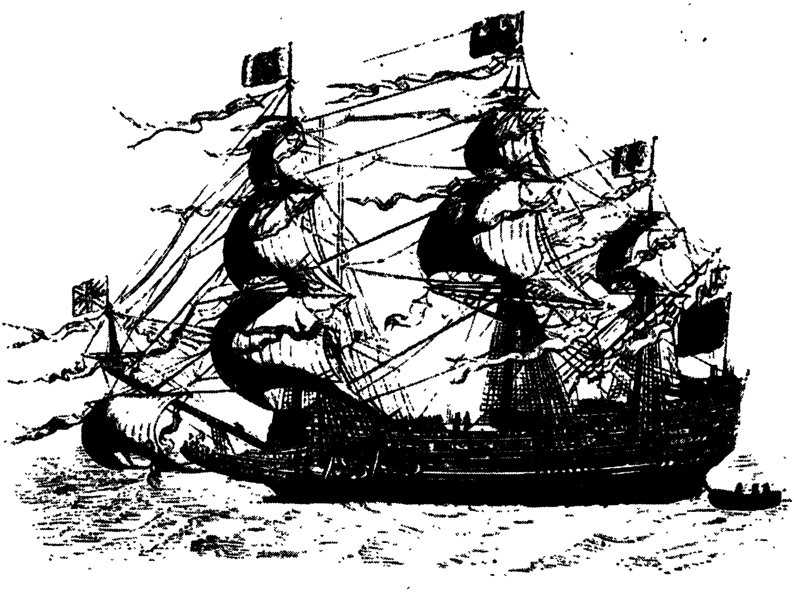
16

DOWN TO THE SEA IN SHIPS

THE CRAFT OF SHIPBUILDING

THE belief that the maritime traditions of the British go back to the very earliest history of the country is not easily supported by facts. Like most generalities, it is too sweeping. True it is, of course, that a people surrounded by water and beset by innumerable rivers and swamps must master the arts of travel by water if they are to flourish, but on the whole the early Britons managed fairly well without either war or merchant vessels. Trading enterprise brought foreign ships to British ports, and conquests brought the Romans, Saxons, Angles, Jutes, and Danes. In neither form of activity does there seem to be much evidence that the inhabitants of Britain considered it necessary to go farther than the coast.

Alfred the Great saw the value of sea power after the bitter lesson of Danish ships moving unattacked far up the tidal rivers. When he built ships, he built them better than the enemy, and his fleet fought with success. The vessels which are illustrated in the Bayeux Tapestry are very little different from those which Alfred built for use in the Channel and North Sea ; and the English evidently had nothing to outclass these Norman ships. Shipbuilding had been going on, however, in the intervening period, for Richard could assemble 150 transports to take him on his Crusade, even though he had to buy sixty more in Venice. By the time of Henry V, 1,500 ships were available for the King's expeditionary forces, and he also built large ships at Southampton. One of these, the *Grace de Dieu*, was built by Huggekyns, the King's master carpenter, in 1418. She had a keel of 112 feet and her tonnage was 1,400. Such a ship was unique and very few vessels of such size were built until the middle of the seventeenth century.

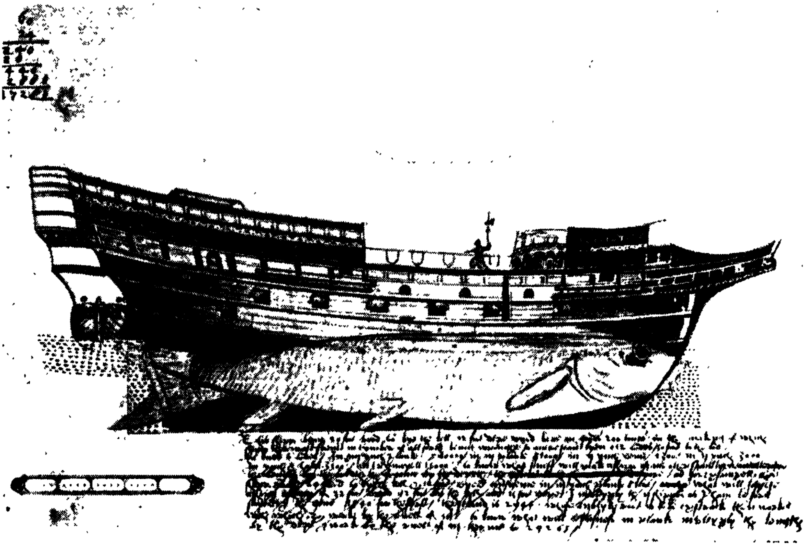


72 The *Sovereign of the Seas*, greatest shipbuilding triumph of her day and the work of Phineas Pett.

Henry VIII was the great sponsor of English ships after Alfred. In his reign the dockyards of Woolwich, Deptford, and Portsmouth were started or extended, and skilled shipwrights from abroad were invited to help those English families which by tradition built vessels for war and trade. Not only did Henry start an organisation later called the Board of Admiralty, but by his charter to Trinity House in 1514 the merchant navy was put on a proper footing. Despite Henry's work, Queen Elizabeth I found that her navy had less than 8,000 tons of shipping, and the merchant navy less than 50,000 tons—some 800 vessels of all sizes, and most of them far less than 100 tons. But the skill was there and the men were ready to build good ships ; when the Armada came 163 merchant vessels were available to aid the tiny English Navy of thirty-four sail.

The master shipwrights of this period are the real pioneers of the industry. In most cases the family has to be honoured, as the skill is handed from father to son. James Baker was the founder of the shipwright family of Deptford and Woolwich. Henry VIII gave him an income of 4*d.* per day (about 8*s.* by to-day's standards) in 1538, this sum being doubled later. His son Matthew, born in 1530, changed the time-honoured system of building a ship by instinct. He lived for eighty-three years and in that time built scores of famous ships, making "plots" beforehand. It was he who suggested the tonnage system of describing a ship's size—the number of Bordeaux casks which could be stowed in the hull.

An equally famous family of the period, the Petts, had a shipyard at Harwich where they had built boats for generations before Peter Pett, with a Government contract, removed to Deptford. Here the most famous member of the family, Phineas Pett, was born in 1570. As master shipwright to the Queen from 1582, Phineas's father was a man of considerable position and wealth, and he could afford to send his son to school at Rochester and Greenwich—an educational routine, in those days, normally provided mainly for those entering the Church or law, and presumably this was the ambition of Peter Pett for his son. However, the father died, and at the age of twenty Phineas, with the degree of M.A., took the unusual course of becoming a shipwright's apprentice, and in 1592 he joined a privateer, working in the Levant seas, as a carpenter. This lasted two years ; Phineas returned to England destitute. Later he worked for Matthew Baker, and in 1602 he built his first merchant ship, the *Resistance*, at Gillingham. He was an ambitious young man and took the opportunity of making the acquaintance of people of influence. One result was that he was asked to build a miniature ship for the young Prince Henry to amuse himself with on the Thames. It was only 25 feet long, but a perfect replica of a large vessel. This pretty little effort would be of little historical importance except that it was the first example of a move towards the construction of a scale-model prototype. The toy for the Prince was followed by another model. This effort gained Phineas a commission to build a full-size ship on the same lines. Pett's influence at Court was resented by the other shipwrights because of his lack of long training.



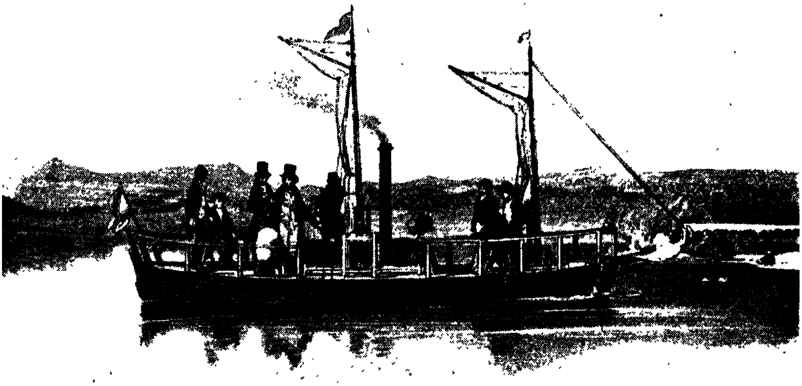
73 Drawing of a galleon with a cod's head and mackerel tail superimposed to show the derivation of the ship's design.

Nevertheless, he maintained his position for many years. His best-known Navy vessels were the *Prince Royal* and the *Sovereign of the Seas*. The latter, built from timber brought from Newcastle and Sunderland, was the biggest ship up to that time. Her trials took place in 1638. On the outbreak of the Civil War in 1642 Pett forgot his ties with the Throne and joined the Parliamentarians, handing over his mighty ship at the same time. He became a Commissioner of the Navy and died in 1647.

A member of another Harwich family followed Pett as the most notable shipwright of his day. He was Anthony Deane, born in 1638, and later a friend and colleague of Pepys, who makes many references to him in his diary. Deane began work at Woolwich under Christopher Pett, son of Phineas, and in 1664, at the age of twenty-six, he was building ships at Harwich. Four years later he was master shipwright at Portsmouth and while working there wrote his famous *Doctrine of Naval Architecture*, one of the first and best theoretical treatises on shipbuilding. In the following years he held various important naval posts and was knighted for his services, but along with Pepys resigned his office because of trumped-up charges of treason. In 1680 he started work as a private shipbuilder. By 1686 the Government wanted him back, and he was doing so well that he could name his own terms. He was at this time earning £1,000 a year, a very large income indeed for those days, even if, as he said, he had " fifteen children to support and was expecting more ". Although he did return to the Navy, political troubles after James II's flight in 1688 once again sent him into the wilderness, and little more of him is known. He died in 1721.

In the seventeenth century English merchant ships increased vastly in number. When Queen Elizabeth I died the great port of London could boast of only ten vessels of more than 200 tons, and foreign vessels (principally Dutch) were carrying both exports and imports. This situation alarmed the merchants, and a great period of construction began. Within twenty years scores of vessels were launched every year, particularly for the coal trade, Newcastle alone having 100 of more than 200 tons burden, capable of transporting 400,000 tons of coal a year from the Tyne. There were also many fine ships built for the East India Company, though most of these were small, the standard as late as 1750 being below 500 tons, because any vessel of larger size than that was compelled to carry a chaplain !

Other merchant vessels were also restricted in size, at some periods, by law, presumably because the Admiralty desired to restrict the use of timber. Wood was in short supply from the time of Elizabeth partly on account of the heavy consumption for shipbuilding (a large naval ship took 2,000 oak trees, each of 100 years of age) and also for the infinitely greater demands for iron-smelting (80,000 trees a year were being felled for this purpose in Sussex alone in the later years of Elizabeth's reign). The result was that, though many ships were built, designs did not greatly alter. Throughout the eighteenth century no important patent on shipbuilding was registered, and during the Napoleonic Wars ships which had been built during the reign of Queen Anne were quite suitable



74 Patrick Miller's double-hulled steamboat built for him in 1788 by William Symington.

for work. Even Nelson's *Victory* was forty years old when she fought at Trafalgar, and was none the worse for that. Merchants had to be content with ships which were both aged and small. The ships which sailed between the Old World and the New were still around 250 tons, and they were taking much the same time for the Atlantic crossing as did the *Mayflower* nearly two centuries earlier.

The Machine Age did not at first affect the merchant ships of Britain very greatly beyond giving them more work to do. This work was not quite as great as one might suppose. The East India Company had a monopoly of the Eastern trade, and for a long period the Napoleonic Wars restricted traffic to a large part of Europe. There was, of course, the American trade, but after the revolt of the colonies the Americans themselves started to gain an ascendency on the Atlantic routes.

The defeat of sail was very near. To-day it is the fashion to show nostalgia for the good old days of real seamanship when engines did not exist. No such sentiments would be echoed by the emigrants battened under the hatches of an America- or Australia-bound barque, nor by the deck hands.

Of all the industries affected by the Industrial Revolution, shipping had the least adverse effects on the welfare and happiness of the employees, which could not anyhow have been worse. The coming of steam meant safety, shorter voyages, and better pay.

A Spaniard named Blasco de Gary is supposed to have made a model steamboat in 1543, and Jonathan Hulls patented one in England in 1736. Such ideas were merely novelties and of no practical value until Watt's steam engine had been perfected. Thereafter the development of the steamship was rapid because the stationary steam engine required little alteration in a ship in contrast to the problems of adapting it for land traction.

The two names in the early development of the British steamship are Patrick Miller and William Symington. Miller was a banker in Edinburgh who engaged Symington to build a steam-propelled vessel in 1788 which duly sailed along the Forth and Clyde canal at seven miles an hour. Symington, a mechanic, was born at Leadhills, Lanarkshire, in 1763. After his work for Miller, the two men seemed to have lost interest in their project, and it was not until 1801 that Symington, by then an engineer to Lord Dundas, Governor of the Forth and Clyde Canal Company, began construction of a better vessel which was planned to haul two canal boats. The ship was completed in March 1802, and named the *Charlotte Dundas.* The horizontal engine drove a single paddle wheel fixed near the stern, rather on the style of the river boats on the Mississippi immortalised by Mark Twain and dozens of Hollywood " period " films. The *Charlotte Dundas* was a great success. It hauled its two boats of 70 tons burden a distance of twenty miles against a head wind in six hours. Unfortunately, the wash from the paddle wheels churned up the soft mud of the canal banks, and the directors of the canal company considered that the cost of repair work would be greater than any saving from the speed and efficiency of the steamboat. The *Charlotte Dundas's* brief day was over. There still seemed hope for Symington, because one of the spectators of his trial trip had been the Duke of Bridgewater, who considered that no real damage to the canal banks had occurred. He sought out Symington and promised an order for eight similar boats to be used on his famous canal. Once again ill-luck dogged the "Father of the Steamboat"; the Duke died before the order had been put into a formal contract, and the chance of advancing the use of steamers by some ten years was lost.

There was another spectator at those trials on the canal —Robert Fulton. He was a painter, born in Pennsylvania, who came to England to study art in 1786. The onrush of invention which he saw on every side influenced him to give up all thoughts of being an artist, and he devoted his life to invention. Understandably, at that time he was no particular friend of this country, and on the outbreak of the Napoleonic Wars he went to France, where he put forward suggestions to aid Napoleon. One of them was to build rafts propelled by steam to be used by the invading French.

In 1803 he built a steamship which was launched on the Seine and promptly sank. Fulton had made careful notes on

75 Symington's *Charlotte Dundas* successfully made her trials as a tug boat in March, 1802.

the Symington ship, and when he returned to America he took with him an engine built by James Watt. This was installed in a vessel in 1807. The engine drove six paddle wheels, and by September of that year the *Clermont* was making a regular passenger service on the 150-mile run between Albany and New York. This British-engined ship was the first commercial steamer in the world.

In this country the first steamship to ply for public hire was the *Comet*, built by Henry Bell, a Glasgow engineer, in 1812. Bell had worked on the first vessel built by Miller and Symington, and he spent most of his energy from that time until his success in trying to overcome both the technical and business problems. The latter were the greater, and it was difficult for an unknown Scots engineer to contradict authorities like the President of the Royal Society, who announced in 1800 that the proposal to drive a ship by a steam engine " was a very pretty plan, but there was just one point overlooked, that the steam engine requires a firm basis on which to work ". This sort of expert view destroyed all chances of Bell obtaining Admiralty help in building his steamboat, and he returned to Glasgow, scraping enough money together to build his tiny little boat : it was a mere 40 feet long and the engine developed 4 h.p. The *Comet* ran between Glasgow, Greenock and Helensburgh, making its first trip on 5 August 1812, to the delight of the brave souls who boarded her and the terror of the crowd on the banks.

As might be expected, the ship-owners who had rejected the idea of a steam-powered vessel as an impracticable stunt now rushed around to the engineering works of the country to buy engines as fast as they could be made. Scotland, which had mothered the men who fought for years for recognition of a device which could make ships independent of wind and tide, justifiably led in early steamship construction in Britain.

The first crossing of the Atlantic by a real steamship was a double event—the *Great Western* and the *Sirius* arriving in New York Harbour on the same day in 1838. The *Sirius* took eighteen days and the *Great Western* fourteen. Before this time Britain was easily leading the world in the construction

76 In 1845 the Royal Navy tested the relative powers of paddle and screw by tying two vessels stern to stern. Both had engines of 200 h.p. The screw-driven ship won easily.

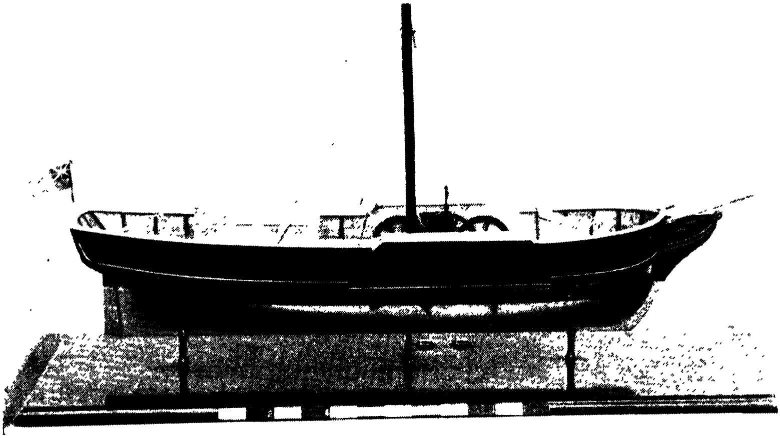
of ocean-going steamships. They were sailing between Scotland and Ireland in 1818 and to Portugal and Gibraltar in 1826. Arthur Anderson, son of a Shetland crofter, who went to London to seek a living in 1815 after his discharge from the Navy, was the driving force behind maritime enterprise in the next twenty years. In partnership with a shipbroker named Wilcox, he founded what eventually became the famous Peninsular and Oriental Steam Navigation Company. This was the beginning of the era of big ships—first of wood and then of iron. They staggered a world trying desperately to absorb the progress of constructional engineering. Of all the projects for bridging great rivers, spanning the earth with railways, and turning out uncountable quantities of machine-made products, the Brunel vessels best captured the public's imagination. They were the *Great Western*, the *Great Britain*, and the *Great Eastern*—great in conception as well as name.

The first, the *Great Western*, was a wonderful ship, even by the standards of to-day. The idea came into being when the directors of the Great Western Railway met in London in October 1835. While some of these gentlemen were shaking their heads about the "enormous distance" which the line was planned to cover between Paddington and Bristol, the railway's engineer, Brunel, quietly suggested that so far from being long enough it should be extended by having a steamboat from Bristol to New York. It was a typical suggestion from this *enfant terrible* of the engineering world of his day.

Isambard Kingdom Brunel was born in 1806, the only son of a Frenchman who had fled to New York in 1793, taking up an engineering post in that city. He came to England in 1799 and played a large part in installing steam-powered machinery in the Royal Naval Dockyards. His son was educated at a school at Hove, Sussex, and showed his interest in engineering affairs by making boats. After further education in Paris, he started to work with his father, whose firm in London was busy building bridges and making plans for a tunnel under the Thames. When the latter project began in 1806, young Brunel was one of the engineers in charge. At the age of twenty-four, his plans for a suspension bridge over the Clifton Gorge near Bristol were accepted, and this magnificent work so impressed the financial interests in Bristol who were planning a railway to London that the young man was put in charge of the project.

The very night after he made his suggestion for a Great Western steamship he started on the design. The first report was submitted to the directors on 1 January 1836, and soon afterwards construction began at the Patterson shipyard in Bristol. The wooden hull was 205 feet long, and the engines drove paddles. For eight years after her maiden voyage in April 1838, the *Great Western* ran regularly on a fifteen days out and fourteen days in schedule, and afterwards she was sold to the West India Steam Packet Company, who ran her until 1857, when she was broken up.

The *Great Britain* was started in July 1839; she was built mainly of iron and was driven by a screw. The Company met an unexpected drop in revenue from the *Great Western* because Samuel Cunard, a Nova Scotian, started his steamship



77 Model of the country's first steam passenger vessel : the *Comet* which plied on the Clyde in 1812.

line and gained the mail contract previously rejected by the *Great Western's* owners, as well as a large slice of passenger business. This financial crisis delayed completion of the *Great Britain*, and it was not until 1845 that the ship sailed from Liverpool to New York. On the return journey she broke her screw in a storm and limped home under sail. In 1846 she went aground off Ireland, and when she was refloated she was sold and transferred to the Australian run in 1851, where she was still one of the crack ships twenty years later.

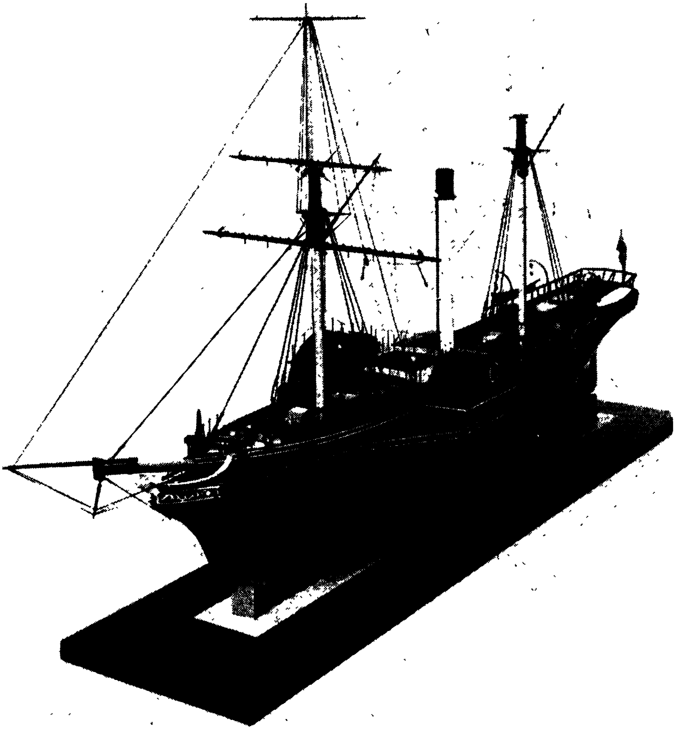
The tale of mishap had one good result. Even though she had been pounded for two years when she lay virtually derelict and aground, her iron construction stood the strain, and this helped Brunel to sell his idea of a mighty ship to be called the *Great Eastern.* It was 680 feet long and of gross tonnage of 18,900. It had engines for both paddle wheels and screw totalling 6,600 h.p. The *Great Eastern* was built at Millwall and was launched (or, rather, launched herself on an unexpectedly high tide) in 1858. Brunel, who was in ill-health, did not see the launching, though he was back from a holiday in Egypt in time to see her move down the Thames and on some of her Channel trials before his death on 15 September 1859.

The man who built the *Great Eastern* for Brunel was J. Scott Russell. It was the most formidable engineering job hitherto attempted, necessitating the making and fitting of tens of thousands of pieces, for none weighed more than 7 cwt. in the mass of 10,000 tons of metal.

Scott Russell, it need hardly be said, was born north of the Tweed—at Glasgow in 1808. His father intended him to enter the Church, but his aptitude for science (he took his science degree at the age of sixteen) put him on an academic career. After teaching science for some time at Glasgow University, he was asked to experiment with steam tugs for canals, and for this work he built his first iron ship. In 1836 he became shipyard manager at Greenock and built ships for the Royal Mail line. In 1844 he went to London, where, among other activities, he was Joint Secretary of the Great Exhibition of 1851. A classic work on shipbuilding, *The Modern System of Naval Architecture*, published in 1865, and the founding of the Institution of Naval Architects in 1860 are two of Scott Russell's contributions to the science of ship construction.

The *Great Eastern* was not a success as an Atlantic ferry, but before she ended her life rather pathetically as a sort of show boat on the Mersey she had brought success to the Herculean task of laying the Atlantic cable. There was nothing wrong with her construction ; the problem of powering such an enormous vessel economically was the root cause of commercial failure, and when this difficulty had been overcome shipwrights had an example of big ship building which made possible the giants of the Atlantic service of later years, culminating in the *Queens* of to-day.

The perfection of the steam turbine by Sir Charles Parsons brought a revolution to fast transport on water. His first turbine was built in 1884 and developed 5 h.p. at 18,000 revolutions per minute. This engine was used to drive a dynamo, and the first Parsons turbines were used to generate electricity at the Royal Jubilee Exhibition of 1887 at Newcastle-on-Tyne. To-day, of course, one of the principal uses of the turbine is in the production of electrical power, and the principle of a continuously revolving engine which Parsons gave to the world has made the large-scale generation of current in hydro-electric schemes possible.



78 A transatlantic steamer of 1838: the *Sirius* which made the East-West passage in eighteen days.

At the time of its invention it was the power of the turbine as a marine engine which captured the public's imagination, which was not surprising in view of the way the inventor proved its efficiency. The Hon. Charles A. Parsons, sixth son of the Earl of Rosse, was born in 1854. His wealthy father was a well-known scientist, and had a lavishly equipped group of workshops at Birr Castle, Parsontown, where he built the Rosse telescope. His son went to Trinity College, Dublin, and then to St. John's, Cambridge, where he passed out as eleventh wrangler in the Mathematical Tripos of 1877.

His first engineering work was with Sir William Armstrong of Newcastle, and his work on the turbine began when he went into partnership with Clarke Chapman at Gateshead.

Three years of work went into the construction of the *Turbinia*, a ship 100 feet long and weighing only 45 tons. But within its deceptively modest hull was a coal-fired engine producing 1,600 h.p. The vessel was completed in March 1897. The tests were kept quiet, for Sir Charles had conceived an audacious plan which, if it had failed, would at the best have resulted in his social ostracism and at the worst might have brought about his arrest.

1897 was Diamond Jubilee year. A highlight of the celebration was the Naval Review at Cowes. Line upon line of the might of Britain's Navy, the invincible force which took *Pax Britannica* to every corner of the globe and guarded the freedom of the seas, were ranged in homage. The *Turbinia* slithered into the great path of sea water between the ships along which the Royal Yacht was to pass. Picket boats angrily bustled out to warn the trespasser to turn back. Thousands of people, including the Royal Family, half the crowned heads of Europe, and last but not least the Lords of the Admiralty, watched the *Turbinia* gather speed until it was crashing along at thirty-four knots, the picket boats left far behind. It was a publicity stunt worthy of the modern advertising agent and carried out with far more justification. The turbine, which might otherwise have been debated and criticised in interminable conferences and then shelved until some other country proved its worth, became a priority to maintain Britain's technical and tactical supremacy in her maritime arm. Soon destroyers were equipped with turbines, and by 1910 1,000,000 h.p. in our ships were produced by turbines, including one of the greatest ladies of the Atlantic ferry, the Cunard *Mauretania*. To-day nearly all warships and the fast passenger ships, ranging from the cross-Channel ferries to the Atlantic greyhounds, are driven by the engine which both shocked and impressed the crowds at the '97 Jubilee Review.

The Parsons turbine, with its capabilities of unheard-of speeds, accentuated the need for scientific study of the movement

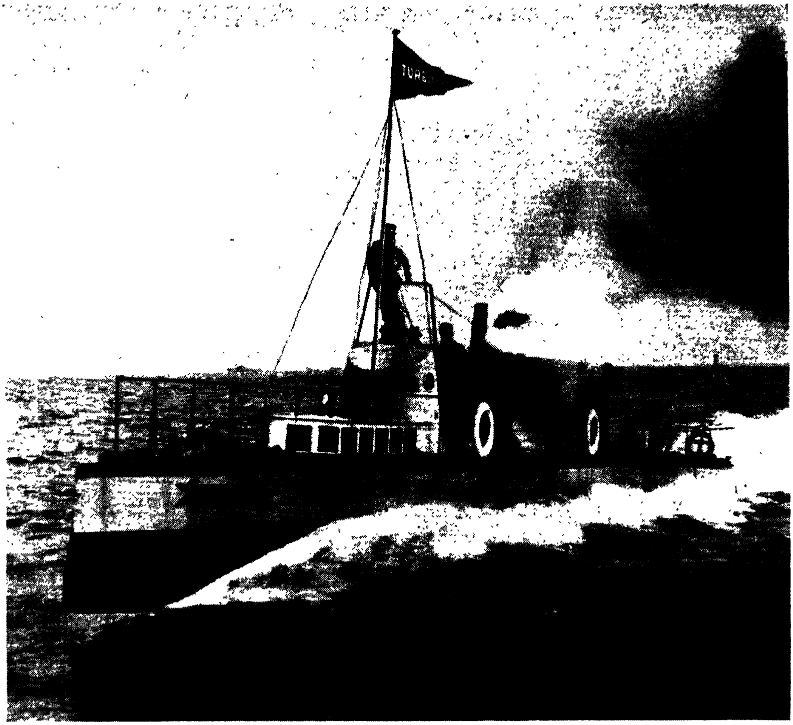
79 Photograph taken in 1858 of Brunel with the launching chains of the *Great Eastern*.

of bodies through water in order to avoid waste of effort. It sounded the doom of instinctive shipbuilding—at least so far as hide-bound tradition to the exclusion of all else was concerned.

There can be no question that in the post-war period Britain has emerged as the great shipbuilding nation. Replacement of the tonnage sunk during the war has kept the shipyards busier than in any period of their long history. Not only have we been building ships for our own merchant fleets, but for overseas countries as well, for we can build ships more quickly, more efficiently and more cheaply than anyone else. This is primarily due to the marriage of tradition and science.

There is a colourful story (at least, the identity of the optimistic owner of such misplaced energy has not been discovered by the author) that an expert mathematician worked for several years on hull design and eventually produced by pure theory a ship design 200 years behind contemporary instinctive plans. The point is valid if the facts are untrue. Shipbuilding, as the families of four centuries ago well knew, is something of an instinct. But it is as well to check on instinctive actions when a few million pounds are involved. Britain takes this precaution.

The ships that Britain will be building three years from now are already afloat—as models. Warships, tankers, coasters, and liners which will make the yards of half a dozen towns hum with activity are going through their final paces on an "inland sea". The research which will give future work to thousands of men, and help to maintain Britain's reputation as the best and busiest shipbuilding nation in the world, is carried on in the Ships Division of the National Physical Laboratory at Teddington, near London. Here are two great tanks which look rather like a section of a canal. Overhead is a travelling bridge crammed with delicate recording instruments. At the end of each tank are machines to make storms, and there are special areas to create conditions of shallow rivers or racing currents. In a typical case of model-testing, the blue-prints of the new vessel, with details of its specialised use, power unit, and estimated cost, go to the experts. From these details a perfect model is made in wax. The size is reduced to that of a small rowing boat. Ingenious machines called pantographs shear away superfluous wax until the shape of the hull is a perfect replica of the ship-to-be. Tow-lines are fixed from the bridge over the tank, recording instruments are attached, and the engineers start up the motor. Instruments record the water resistance at various points along the hull, and if the figure is too great the wax is shaved off until the best performance figure is obtained. Next a motor is fitted into the model corresponding to the power of the engines which will be fitted to the actual ship. Different types of propellers are fitted, and as the model cruises about the tank wires to the engineers' bridge over the tank give exact details of



80 The *Turbinia* attained a speed of 34 knots in 1897—faster than any vessel had ever moved on water before.

revolutions, speed, thrust, and torque. Tests go on day after day in head winds, heavy storms, and at different water temperatures. Steering comes in for a lot of attention, and the finally approved model will invariably be very different from the original design.

Tests of the ship model take about a month and cost around 200 guineas for a comparatively simple design. The time and money saved is incalculable. Mercantile shipping concerns are not anxious to give figures, but typical of the improvements which Teddington can give were quoted by Dr. S. L. Smith, Director of Research of the British Shipbuilding Research Association. The battleship *Queen Elizabeth* had an endurance of 4,400 miles at ten knots on her completion in 1915. Reconstructed in 1940, her range at this speed had been increased to 13,000 miles with only a slight increase in fuel consumption.

The man who pioneered this method of model-testing on a scientific basis was William Froude. He was born at Dartington, Devonshire, in 1810, one of a family of eight who later shone in several branches of knowledge and culture. William became a noted classical and mathematical scholar at Oriel College, Oxford, and he stayed at the University until he was twenty-six, principally to study the movement of ships in water. Then he worked with Brunel on the Great Western Railway, and when the latter built his ships Froude was asked to contribute his technical knowledge. He made a special study of the likely behaviour of the *Great Eastern*, and he sailed on her trials, advising that bilge keels should be fitted to limit the rolling. Then he returned to his home and devoted all his time to this study of wave motion, moving in 1859 to Paignton, where he had testing tanks in the attic and in his garden.

The ratepayers of the nearby town of Torquay had good reason to appreciate the knowledge of the movement of water which this retiring man had gained, for he was able to double the supply through the pipes without laying new ones, his advice having been requested when the mains were almost choked with sediment.

It was not until 1867 that the Admiralty came along to see what he was doing. The upshot was that he was given £2,000 to build a tank for the testing of large models. The entire sum was absorbed in merely constructing it, and the invaluable work which came afterwards was carried out entirely at his own expense. Two results of a body moving through the water were Froude's special study. One was the friction of the water on the skin of the ship and the second was the wave pattern. Each model was of two types—one severely streamlined and the other an approximate imitation of natural surface-swimming bodies, such as water fowl. Not only did he show that shapes that seemed all wrong by conventional shipbuilding standards might offer very little resistance at certain speeds, but he worked out the equations which enabled designers to use his discoveries in their plans. The intricate recording machines and the motive power for the models were of his own design and construction, even though most of the work was done after he was sixty years old. By the time of his death in 1879 the use of models to test designs was accepted as normal precaution against failure, and his son was able to carry on the work in an official capacity at the Admiralty Experimental Works at Haslar.

From the shipyards of Alfred the Great to the stocks of the Clyde, the Tyne, the Wear, and Tees of to-day has been a long journey. The names of the men who have made it a story of success are legion, and necessarily in this account it has been possible only to mention a few of them. It might well be that the real builders of our supremacy in this industry can best be found by walking into the yards of to-day, where the staccato roar of the riveters goes on perpetually, and if we pause and talk most of the craftsmen can say proudly that their families were building ships from a time lost in recorded history and known only by tradition and the inborn talent which generations have bequeathed to the men whose bedlam of noisy activity is a song of success.

81 Shipbuilding, from a medieval MS.

17

WATERY WAYS

PIONEERS OF CANAL CONSTRUCTION

IT was not, of course, an accident that the ancient communities in Britain settled beside a river. The early social and economic history of this country flowed gently along with the current of the fine waterways with which Nature had enriched the land, and apart from the prehistoric settlements of Salisbury Plain, set on high ground because defence was more important than trade, the rivers of Britain were the main carriers of goods to a far greater extent than the network of roads which the Romans found, adapted, and improved when they arrived.

It must be remembered that all rivers were wider than they are now. Forests and lack of drainage kept the rivers broad and slow-moving, and hundreds of the streams of to-day were formidable waterways. When the Danes made their periodical swoops on these islands from the ninth to the eleventh centuries they were able to sail their ships far inland. They could approach almost to Bedford up the Norfolk Ouse, to Worcester along the Severn, and as far as Hertford on the Lea.

In mediæval times the importance of keeping the waterways clear of shoals and similar obstructions was recognised, particularly in the case of the Severn, which was a free river as far as boats could go. In fact it was known as a King's High Stream, just as the roads were known as the King's High Ways. This traditional importance of the Severn, plus the large numbers of expert carriers who lived along its banks, was a contributory reason for the early industrial prosperity of the Midlands. The water artery was the only feasible method of transporting heavy material from inland manufacturing sites. Stone for the wonderful religious buildings of the

Midlands and West Country went along the Severn, and centuries later, when Boulton and Watt were building steam engines for use in the Cornish tin-mines, they were floated down the Severn on rafts.

Other rivers, notably the Trent, Thames, and the Yorkshire Ouse, were similarly important. They performed their function well until manufacturing processes became more involved. Production of iron and the making of pottery were severely restricted because large supplies of two raw materials were needed in each case. Iron manufacture had to remain where the ore was to be found, in places like Sussex and the Forest of Dean. Potters were confronted with the quandary of working where the coal was or where they could find the suitable clay. They remained near the coal and brought the clay from Cornwall at enormous trouble by long trains of pack-horses. If it had not been for the problem of transport, the Industrial Revolution might well have arrived a century before it did. When it became possible to supply the manufacturing zones with raw materials and to take their masses of products, it was because a few men had constructed artificial waterways to link the rivers of England.

It is doubtless a reflection on English enterprise that the first great waterway improvements were carried out by Dutchmen working in this country. Cornelius Vermuyden was the greatest of these men. His labourers were Dutch and the necessary finance came from the mercantile houses of Amsterdam. Vermuyden carried out large drainage works on the Severn in the Sedgemoor and Malvern Chase areas, and in 1629 the Norfolk authorities decided to commission him to drain the vast area of the Fens known as the Great Level. Vigorous objection was made to giving a foreigner this work, and the Earl of Bedford was appointed instead of Vermuyden. It was merely a formal change, for the Dutchman and his Flemish workers actually did the work. The navigable rivers which emerged from the swamp needed constant attention. As they did not get it, the whole area soon reverted to its previous state. Then, in 1634, Charles I personally intervened and appointed Vermuyden to work with an unrestricted hand. Oliver Cromwell, Member of Parliament for nearby Huntingdon, must have seen the wonderful work that was being done, but he or his friends dismissed the practical value to the nation of the work and used it as a political weapon. Charles I, it was suggested, was usurping his powers in ordering this land reclamation. The men of the Fens rose up and cut the embankments, and in a matter of hours undid the toil of years. Vermuyden sat quietly by, and in 1649, once more under the nominal control of the Earl of Bedford, and with the help of many hundreds of Scottish prisoners taken in the Civil War, the work began again. Three years later 40,000 acres of the richest farmland in Britain were ready for tilling. Navigable canals and rivers brought prosperity to East Anglia (then the most densely inhabited area of provincial England), and the Dutchman who had achieved this great engineering work in the face of local opposition and during a time of civil war was belatedly rewarded with a knighthood.

Shortly after this, numerous river works were undertaken. Sir Richard Weston improved the Wey so that boats could be used from its junction with the Thames as far as Guildford, and Andrew Yarranton of Astley (near Stourport) made the Stour navigable from Stourbridge to Kidderminster, probably the first engineering enterprise with the deliberate purpose of making coal transport easier. He also had a scheme to build a canal to link the Trent with the Severn which fell through because of lack of funds. Yarranton had to finance his work himself. Nevertheless, he is the godfather of the canal system in this country.

The man who caused the revolution of industrial transport by constructing artificial rivers was born in 1716 at Tunstead, near Thornsett, Derbyshire. His name was James Brindley. His father was a farmer—and a failure. The large family had to fend for itself as best it could, and its efforts to keep alive did not include education. But Brindley was a natural genius, an engineer born for his profession who would have inevitably made his name in industrial history. He slaved in his father's fields until he was seventeen and then persuaded

82 Canal and river meet at Stourport: a contemporary picture of the work of Andrew Yarranton.

a millwright to give him a job. His employer became so incensed at the lad's complete illiteracy and lack of education (he counted with difficulty) that he did his best to break the indenture. But within a few months the old man fell ill, his brain gave way, and young Brindley ran the whole business, supporting himself and his employer's family in a greater degree of prosperity than they had ever known before. This millwright business was at Leek, Staffordshire, and young Brindley became well known throughout the area as a skilled engineer who could find the answer to any problem. Mine-owners, potters, and silk manufacturers had a slogan used jokingly as the reply to any problem: "Ask Jim."

This was the reason why his name was put forward when the Duke of Bridgewater, a young man who had found the social life in London distasteful and had decided to devote himself to the welfare of his estates, planned to build a canal. His aim was to transport coal from his mines to Manchester. In 1759 Parliament authorised "An Act to enable the Most

Noble Francis, Duke of Bridgewater, to make a navigable Cut or Canal from a certain place in the township of Salford, to or near Worsley Mill and Middlewood in the manor of Worsley, and to or near Hollin Ferry in the county palatine of Lancaster."

Brindley's heart must have leapt when he heard that the Duke wished to see him, for the farmer's boy was utterly convinced that he was destined by God to build canals, and, further, he believed that Nature had placed rivers in the land for the sole purpose of feeding man-made canals. It speaks well for the aristocrat that, after a brief meeting with the uncouth and fanatical candidate for the job, the bargain was sealed and Brindley was told to walk over the proposed canal route. In his diary he later described this event as an " ochilor servey or a ricconitoring ". A bad speller to the end of his life, Brindley had a love of the longest words he could find—one of the many traits which made him an endearing character to all who met him.

The main obstacle on the proposed route was the River Irwell and its valley at Barton. Bridgewater realised that many locks would be necessary, but did not regard them as an insuperable obstacle. Brindley had other ideas. " We'll take the canal over the river by a bridge," he said ; " then there'll be no need for locks." If he had suggested carrying the coal by air he could not have caused much greater surprise among the engineers of his day. His patron, either through ignorance of the difficulties or an instinctive faith in this self-assured man, agreed almost at once.

It is almost impossible for us to appreciate the size of the task on which Brindley blithely launched, even though his canal was only just over ten miles long. There was no precedent, no authority to consult, no books on the subject even if he could have read them. He had never received any scientific training and had never been in charge of large gangs of men. He simply started digging. Man-power was easy to obtain. Agricultural work was poorly paid and Irish labourers were roaming the country looking for employment. The hundreds of rough-and-ready men who invaded the peace

An aqueduct on the Peak Forest canal built for transport services to the great textile factory of Samuel Oldknow at Marple.

of the Worsley countryside caused as many misgivings as the tamperings with Nature. The navigators, as the workmen were called, became a byword for hard drinking and hard fighting. But the navvy was also a hard worker, and the canal went on apace.

There were no paper plans ; Brindley knew nothing of scale drawing. There were no calculations on the amount of earth to be removed ; Brindley was incapable of working out such problems on paper. When he came up against a difficulty he ordered work to stop while he went to bed. He remained there for a day or so until the solution came to his mind. He had an instinctive ability to know when the answer was the right one, and usually it was simple.

The waterproof layer of puddled clay which lies on the bed of every canal to-day was one of his discoveries. Parliament, wanting to protect the countryside from inundation, doubted that a thin layer of clay would prevent leaks. Brindley went up to London to explain his method to a Committee of the House of Commons. He took a large box of clay with him. The legislators, who expected a deferential and wordy description of the method, were astounded when Brindley took his clay, pounded it into a trough and poured water into it. A viscous yellow liquid promptly ran all over the floor. Then he kneaded the clay with water to imitate his puddling method and once more formed a trough. This time the water was held without a particle of leakage. Brindley left the room with its messy proof that no leakage would occur from his canal. Even if Parliament had been convinced, the people of the North were not. They waited to see what would happen when he reached Trafford Moss in the Manchester district. This area was a wilderness, inhabited only by gipsies. Brindley's puddling process in a channel held by heavy embankments worked perfectly, of course, and the gipsies went to work for him. From this early connection with canal construction, the gipsies obtained jobs on the boats, and this is the reason why so much Romany lore is seen in the designs and furnishing of the cabins of canal boats even today. The fact that the gipsy could still be a nomad, keeping his family around him in a cabin of much the same size as his caravan, made the migration to water easy.

The greatest interest was, of course, in Brindley's Barton aqueduct. Many people in the district packed up ready to move when the water was let in to the waterway of earth and puddled clay carried on a series of massive, squat arches. When the first boat sailed across it in July 1761, crowds were standing in awe at a safe distance, and for months afterwards stage coaches were diverted and stopped so that the passengers could view the greatest engineering feat of the time.

At the Worsley end, Brindley drove a canal right into the side of a hill to communicate directly with the coal-mines, and eventually there was a network of water channels to every part of the workings so that tubs of coal could be floated to the boats without any land transport at all. These channels also ventilated the galleries, drained them, and supplied the canal with water. And so, in the summer of 1761, the faith of Bridgewater in an illiterate millwright was vindicated. Immediately the effects of the canal were noticed in Manchester. The price of coal was halved—from 7*d.* per cwt. to 3½*d.*

Brindley, by that ten-mile stretch of engineering, was established as the first great civil engineer in Britain. A year later the Duke of Bridgewater obtained permission to build a canal from Manchester to Liverpool, which Brindley undertook to construct. Before this was completed, he had surveyed huge areas of the North and Midlands at the request of the industrialists. By his old methods of walking and looking, he outlined in his brain a tremendous plan to link the rivers Thames, Trent, Mersey, and Severn by 260 miles of canals. Before he died at the age of fifty-six at his home at Turnhurst, near Golden Hill in 1772, most of this network was complete. All over the country his work, now almost 200 years old, can still be seen. He built solidly and on principles which no technical theory can improve upon. His navvies, with only the simplest tools, such as pick and shovel, tunnelled through hills, constructed embankments, and enabled boats to move on the level surface of water in districts where hills and valleys are met with every few miles.

Brindley's canals made the industrialisation of England possible. Without them the movements of masses of material on which industry depended would have been impossible or at least prohibitive in cost. To-day the symbol of the canal may seem to be the old-world peace of their placid backwaters. This is fallacious. For bulk transport the advantage of their cheapness far outweighs the defects of their slowness. New life has come to the canals under nationalisation, and their maintenance and improvement are going ahead. Brindley gave our national economy a heritage which has too long been ignored. With a diesel engine, one boat can haul more than 50 tons at a steady six miles an hour. Neither rail nor road transport can compete with this figure. Co-ordination of canal, road, rail, and air transport, so that each plays its rightful part in the conveyance of goods, is now possible. With it Brindley's pioneering work may still provide the wealth it should.

If so, it will be a tardy recognition. The canal monopoly lasted only some sixty years. In that period some large fortunes were made by speculators, but the crash of many ill-conceived imitations of Brindley's enterprises was loud and sudden. It came with the invention of the railway locomotive, the first examples of which were being tested before Brindley's navvies had finished their digging. They, like the investing public, rushed to the new form of transport. Britain, which had been criss-crossed with watery ways, now became a spider's web of iron rails.

18

THE IRON HORSE

EARLY LOCOMOTIVE ENGINES

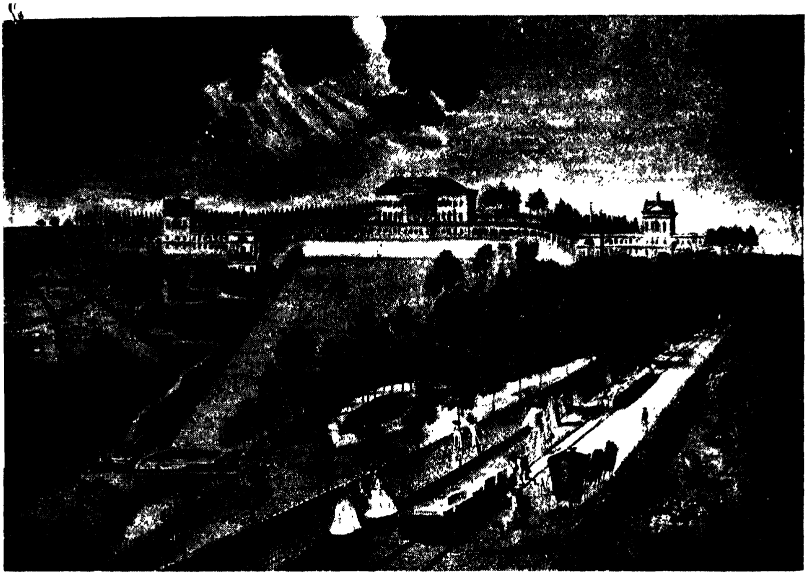
IN these days of air and road transport we are inclined to forget that our civilisation could never have developed in its present form if it had not been for the railway and the steam locomotive. Some historians have put forward the view that canals and mechanised vessels would have eventually reached the same goal many decades later, but this is a doubtful matter in continents outside Europe where waterways would have been prohibitive in cost, even if ingenuity and brute force had achieved their construction. Such theories are, in any event, of merely academic interest, for the railway locomotive was a British invention which quickly bound these islands together, then the continent of Europe, and thereafter the entire world —one of the greatest practical contributions to mankind of English genius. The enormous quantities of raw materials, food, and manufactured goods which were required for the insatiable hunger of an industrial civilisation were carried cheaply and quickly. To-day some freight trains in America do the work of half a million men. The pack animal with a hundredweight or so, moving at three miles an hour, or the lumbering multi-horsed wagon groaning under 2 or 3 tons and covering about three miles an hour, had served mankind for thousands of years. Now, in a lifetime, the pattern of communication was changed completely. Huge numbers of people could live in factory communities, and the railways would bring them the food they needed for life and the raw materials for their work. The first victory over distance since the invention of the wheel by prehistoric man had come.

The principle of a rigid track which gave less resistance to the wheel than an ordinary surface had been known for many centuries before the idea of steam locomotives was first mooted. By the end of the eighteenth century most of the country's collieries had tramways. These had developed from the single line of planks laid down in the seventeenth century, when most coal was brought out of the mines by wheelbarrow. Later the wheelbarrow became a flat wooden tub called a rolley. Its wheels were set very close together so that it could run on the single line of planks, but by the reign of Charles II there were many double lines of wood, and the rolleys had a stout wooden pin on the inner underside near the wheels to guide them on the planks. This idea appears to have come from the German metal mines and was first used in this country in Somerset and Shropshire. But the great mines of Tyneside pioneered the far more practical idea of automatic steering in the flanged wheel.

Some of these mine tramways were of considerable length. Sir Humphrey Mackworth, who owned a pit near Neath, had a track of nearly a mile by 1695. He used sails on his wagons and is said to have thereby saved the use of twenty horses when there was a fair wind. This track ran across the public road and the burgesses of Neath pulled up the planks and destroyed them. In a subsequent court case at Cardiff their action was upheld, the jury declaring the track a " nusance ".

Cast-iron rails were being used by 1795, by which time the wooden wheels had also been replaced by iron ones. The outbreak of the Napoleonic Wars encouraged even the most conservative of mine-owners to lay down these railways, because forage was short and horses became expensive. Economy on expenditure in these two categories, once so cheap that the capital expense of iron rails had hardly seemed worth it, became of paramount importance. It was this shortage of horses which accelerated the search for mechanical motive power.

It will be appreciated, as explained in the story of James Watt, that the steam engines in use in virtually every mine in the country as well as in many spinning and weaving plants were of the low-pressure, condensing type and of enormous bulk in relation to their power. Their efficiency was far too

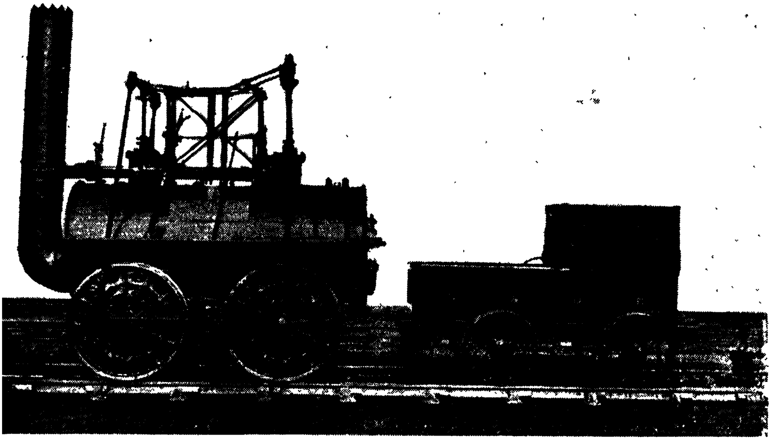


84 The earliest known view of an English railway—running alongside the estate of Ralph Allen near Bath. The date is *c.* 1750.

low to make them a practical possibility for mobility, though William Murdock made a model which ran amok in Redruth's main street, and frightened a parson into hiding in the ditch. The need to extract more power from steam pressure was realised by Richard Trevithick, who is the real inventor of the steam locomotive. With his name should be linked that of his cousin, Andrew Vivian, who was Trevithick's partner in the experiments made as the nineteenth century dawned. Trevithick, who was born at Camborne, Cornwall, in 1771, and knew all about Murdock's experiments at nearby Redruth, was interested in road transport—not unnaturally, as this was the era of the mail coach, spinning along the roads of Britain, much better surfaced by this time owing to the work of the turnpike trusts, at a cracking average of twelve or even fifteen miles an hour, but at an enormous cost in horses, with an average of one animal for every mile of coach route. Trevithick made a model locomotive in 1796 which marks the real beginning of efficient steam traction, with the doubtful exception of a small locomotive made by a Frenchman named Cugnot which journeyed through the streets of Paris one day in 1763 until it crashed and was hastily removed as a menace to the public. There was a fundamental difference about all Trevithick's locomotives and all others : they worked.

The 1796 model was a tiny product, which his friends dismissed as just a toy when they saw it chugging around the table in his workroom. The full-size " Puffing Devil " which he built next was a road vehicle. It was burned by an irate mob—presumably horse-lovers—while Trevithick and his friends were celebrating the success of the trip in an inn. In 1802 Trevithick took out a patent for a similar design. The proprietor of the Penydarran Iron Works at Merthyr Tydfil, Samuel Homfray, ordered some high-pressure steam engines for his works and he was so impressed with their efficiency that he suggested that Trevithick should build a locomotive to run on the nine-and-a-half-mile tramway which ran between the works and Abercynon, nine miles away. The first run of the engine, almost certainly the first steam-powered machine to move on rails, and hauling goods, took place on 13 February 1804. The locomotive weighed 5 tons and it was capable of hauling 20 tons of iron at five miles an hour, an enormous saving on horses and a slightly better speed into the bargain. All traces of this historic invention have disappeared and it was not used for very long because the cast-iron plates of the track frequently broke under the weight, and eventually the engine toppled over and was damaged. It should be remembered, however, that there was nothing wrong with the locomotive. It could draw a paying load; it was reliable, and it confounded the critics, who were certain that the track would not provide sufficient grip for the wheels.

Trevithick designed an engine for the Wylam Colliery at Newcastle. This had flanged wheels and if only the track at Wylam had not been of wood the machine should have been a practical proposition, but it seems that it was not actually used. The disappointment of such experiments influenced Trevithick to return to his first interest of steam road carriages. In the summer of 1808 he rented a patch of ground on the present site of Euston Square, erected a high fence and laid



85 " Locomotion ", an 8-ton engine which was running on the Stockton and Darlington line by 1824.

down a circular track for an engine named " Catch Me Who Can " and a few trucks which gave the public a ride at a speed of twelve miles per hour for a shilling fare. Once again track troubles caused many failures, and the public, regarding the whole thing as a stunt, forgot the affair after the show closed in September. Trevithick was only thirty-seven at this time, but he gave up all further interest in locomotive work.

He eventually went to Peru, where he spent some time in installing steam engines for the silver mines. They were not successful, and he returned to England, dying at Dartford, Kent, in abject poverty in 1833. When the workpeople of the Hall Engineering Works in the town heard that Trevithick would be buried by the parish, they clubbed together to buy him a proper grave—the only gesture from a nation then finding great fortunes in the railway boom. Although there is now a window in Westminster Abbey to Trevithick's memory, the location of his grave at Dartford is unknown, for the pennies and sixpences contributed by the artisans from their small wages did not amount to sufficient for a gravestone.

After Trevithick abandoned his locomotive experiments, other engineers, dismissing his stunts of giving the public free rides, concentrated on the basic faults of his invention. John

Blenkinsop, in 1811, tackled the track-adhesion problem by placing a toothed wheel between the two running wheels to engage in a toothed rail laid alongside one of the track rails. The engines were made by a firm known as Fenton, Murray, and Wood, and although the machines were no heavier than the Trevithick engines they could haul a load five times as great. By 1813 these engines were working between Leeds and the Myddleton Colliery and between Newcastle and the Wylam Colliery. At the latter, one of the engines was the famous " Puffing Billy " (the other was called " Wylam Dilly ") and both were in continuous use for more than twenty years.

In the world of coal-mines the hiss of steam was, by the turn of the century, as common as the rattle of coal. The twin elements of fire and water were there to arouse the imagination of any impressionable boy, no matter what his education or lack of it. Such a lad was George Stephenson, born in June 1787 in a one-room cottage near Newcastle. With seven children to feed, Stephenson's father had nothing left from his wages as an engineman at the colliery for the schooling of his children. George grew up without any knowledge of even the alphabet. When more fortunate boys were attending a dame school at a fee of 6*d.* a week, George was minding cattle or hoeing turnips for a few coppers a day. Later, he worked at the colliery as a horse-minder. This job gave him plenty of time to watch the steam engine used at the mine (the Killingworth Colliery) and he used to make models of it in clay. By the time he was appointed engine-wright there was nothing about engines that he did not know—and all the knowledge came from practical observation, for he was a skilled engineer before he had learned to read at a night school. This establishment gave him the rudiments of learning, but he had to wait until he was married and his little son Robert could pass on the gist of his own lessons before he became educated in any real sense of the term.

Stephenson was a man of restless energy—and it was this even more than any inborn talent which carried him into the pages of history. His own childhood gave him a perpetual horror of poverty and the result was that he put his hand to

86 The boggy ground of Chat Moss successfully traversed by Stephenson's Liverpool-Manchester Railway.

anything to earn money. When he was earning 19*s.* a week as a colliery fireman (a very fair wage for the period) he had a galaxy of sidelines to occupy his time at the end of a twelve-hour day. He made and mended boots, repaired clocks, and set up as a tailor ; at week-ends he loaded and unloaded barges. With this anxiety to make money, it is a matter for surprise that Stephenson managed to see far enough ahead to visualise the steam locomotive, but he did—and also ran true to his character by making a fortune into the bargain. He is one of the select band of inventors who was also a brilliant business-man, and no company promoter ever filched the children of Stephenson's fertile mind for his own exclusive benefit.

The period that Stephenson actually devoted to locomotive construction was short—a mere nine years—for after 1822 he devoted his life to railway construction, and the locomotive side was left to his son. But in those nine years the man from a Newcastle hovel proved beyond all doubt the practical utility of the steam locomotive. He began building his first locomotive in 1813, and it was used at Killingworth in the following July, hauling eight loaded wagons on a fairly stiff gradient at a speed of four miles an hour. The feature of this performance was that the engine ran on a smooth iron rail without any rack or gearing. The pistons which worked through gears were both noisy and inefficient, and in partnership with Ralph Dodds, Stephenson took out a patent in 1815 for a locomotive with connecting rods taking the power direct to the traction wheels. In the following years a succession of machines was built, each improving in general efficiency, and particularly on adhesion between wheel and track.

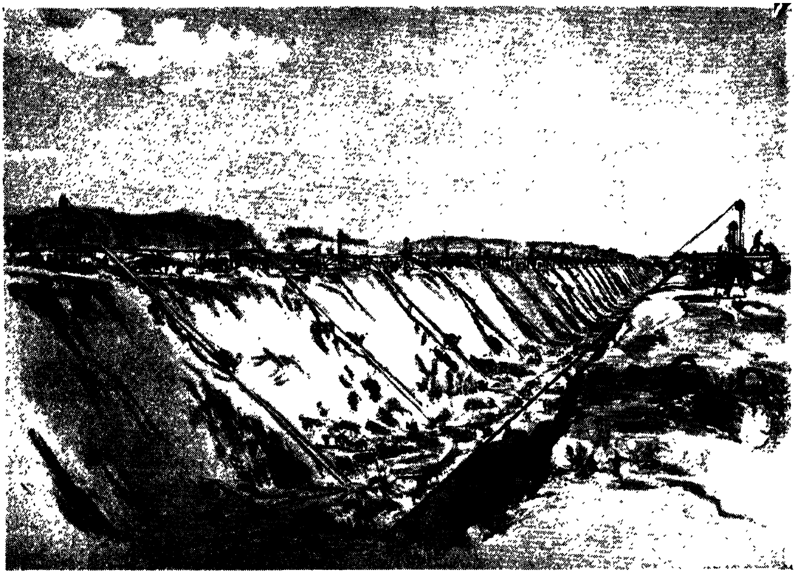
Stephenson was by this time a fairly wealthy man. His resources were amply increased when he was donated £1,000 collected by public subscription as a reward for the Geordie safety lamp for miners which he had invented. In 1821 he heard that Edward Pease had obtained authority to construct the Stockton and Darlington Railway. This was to employ horses to draw the trucks—a retrograde step which Stephenson determined should be put right. He obtained the appointment as engineer to the railway in 1822, and old Pease, who was a Quaker and very cautious in his business activities, was persuaded to apply to Parliament for permission to carry passengers as well as goods—and to haul them by steam locomotive. The Act was passed with some difficulty in 1823, and Stephenson, in conjunction with his son Robert, Edward Pease, and an engineer named Michael Longridge, formed Robert Stephenson & Co. at Forth Street, Newcastle, in June of that year. From the works came an 8-ton engine named "Locomotion" which was running on the Stockton and Darlington line in September 1824.

This short railway, the first public steam-engined line in the world, did not cause much comment outside the locality. The enterprise which was to inaugurate the railway era was the Liverpool and Manchester Railway. Parliament authorised its construction in 1826 after a battle royal which was virtually George Stephenson *versus* the population of England. Many times his life was threatened by landowners. The ordinary public believed implicitly the authoritative articles which appeared in the Press proving that the engines would explode

87 Armies of navvies were employed to build this embankment near Wolverton in 1837 on the London-Birmingham line.

and destroy a considerable area of the countryside, and, before they did so, they would set fire to adjoining fields and woods, and poison the atmosphere. Sporting Members of Parliament complained that fox-hunting would be ruined ; the agricultural interests were certain that cattle would be stampeded; and business circles (which probably saw the danger signal to their recent heavy investments) pointed out that the flourishing canal system was quite sufficient for carrying the nation's merchandise. There were more reasonable doubts about the railway, such as some engineers' belief that there would be no method of laying a stable track across the morass of Chat Moss.

Stephenson fought on, aided by tacit encouragement from the industrial concerns of the North, where men with little political influence but a growing economic power knew that the steam which had brought them prosperity in their textile factories might very well still further enhance business when used for transport. Inevitably, the die-hards had to give way, and the railway was begun, hampered by many deliberately awkward restrictions, such as a clause that any engine used on it must consume its own smoke. To the legislators this may



88 Another view of the London-Birmingham railway construction work: a deep cutting near Tring undertaken in 1839.

have seemed a tall obstacle indeed. Stephenson, in co-operation with Henry Booth, the secretary to the Railway, overcame it by January 1828 with a smokeless engine named "Lancashire Witch". It was used on a private railway between Bolton and Leigh (Lancashire).

Meantime, the work of laying the track of the Liverpool and Manchester Railway went on steadily. When it was nearing completion early in 1829 the directors called a meeting to confirm that locomotives would be used. Reading once again the restrictions and stipulations of the Act which permitted them to operate, they became nervous, and two experts appointed to examine the question reported in favour of a cable railway. Stephenson was naturally disgusted with this attitude, and, with the support of some of the directors, he forced the issue. At a meeting in April 1829, the company issued the details of its historic contest for locomotives to be held on the following 6 October. The prize was £500—plus the contract for the locomotives and world-wide fame to boot.

89 Isambard Brunel, the engineering genius of the Great Western Railway which he ' extended ' by steamship to America.

Five entries were forthcoming. One was a remarkable contraption called the "Cycloped" and worked by a horse. The other four were "Perseverance" (Timothy Burstall), "Sans Pariel" (Timothy Hackworth), "Novelty" (John Braithwaite and John Ericsson), and "Rocket" (George Stephenson and Henry Booth).

The test was a stiff one. At Rainhill, nine miles from Liverpool, a course of one and three-quarter miles was laid out, which included one-eighth of a mile at each end for starting and stopping. Ten round trips had to be made at an average speed of not less than ten miles per hour and hauling three times the locomotive's weight.

The "Perseverance" and the "Cycloped" were withdrawn after a brief attempt ; the "Sans Pareil" broke down. The

"Novelty", which managed one burst of thirty-one miles per hour, also broke down twice. The "Rocket" carried the day, hauling a load of 12¾ tons at a speed of twenty-nine miles per hour. The "Rocket", apart from this outstanding performance, was the only entry to complete all the journeys and fulfil all the conditions, and it was, of course, awarded the prize.

It is noteworthy that this engine, nearly always ascribed solely to George Stephenson, was actually constructed by his son Robert. Apart from a few visits to watch progress, the elder Stephenson was occupied during the whole time of the locomotive's construction with the affairs of the railway. The efficiency of the engine was largely due to the tubular boiler, and this was the idea of Booth. But the moving spirit behind the enterprise was the elder man, and if George Stephenson was not the father of the railway locomotive he was certainly its nurse and sponsor—and the driving force behind its progress towards practical use.

Not the least remarkable point about the invention of the steam locomotive is the short period from the first experiments to a basically perfect machine. The year 1829 marks the dawn of the railway era with the announcement of the Rainhill contest. It is also the noonday of locomotive invention. In the ensuing years development was merely a matter of size and detail, and the adoption in 1833 by Stephenson of six wheels to minimise the pitching motion became a standard design which lasted until 1894, and the engines of this type gave speeds as good as, and in some cases better than, the timetable schedules of to-day.

This headlong development captured the imagination of the public, and the financial escapades of the railway boom, while regrettably filching more money from the public than the earlier canal promotions in scores of ill-advised enterprises, quickly gave this country a magnificent railway system. The lure of speed beyond the previous optimum of that of a galloping horse had come to stay. Small wonder is it that, with distance being annihilated on earth and sea, many imaginative men turned their eyes to the skies as a place to try the power of the machine.

19

CONQUEST OF THE AIR

THE DEVELOPMENT OF AVIATION

MAN has always envied the birds their wings. It is understandable that it was some direct imitation of them which occupied the thoughts of the more inventive in early times. Mythology and folklore are, of course, full of such stories, notably the classical account of Daedalus and Icarus. Less well known is the similar exploit of Bladud, reputed tenth King of Britain, who died as the result of an experimental flight with wings in 852 B.C.

The restless mind of Roger Bacon delved into the subject when he was writing his *Secrets of Art and Nature* in the thirteenth century, and his theories are of interest because they appear to be the first appreciation of the fact that a machine would be needed to provide the motive power to fly, as distinct from an imitation wing strapped to the arms. In this Bacon was further forward than the great Leonardo da Vinci, who in 1505 wrote an erudite study on the flight of birds and tried to show how the mechanics might be imitated by man. In the ensuing years the principles of aeronautics were gradually evolved, but undoubtedly the most practical contribution did not come until the early part of the nineteenth century, when Sir George Cayley, the father of British aeronautics, published " On Aerial Navigation " in the *Journal of Natural Philosophy* for November 1809. This was the result of long and careful experiments begun when he was twenty-two in 1796. They concerned the investigations of the principles of the aerial top, a Chinese spinning toy which, when whirled round, rose in the air. From this simple little novelty he was able to define the problem of machine flight as one of " making a surface support a given weight by the application of power to the resistance of the air ". He, alone of the thousands of people who were vaguely amused at the sight of children playing with these tops, saw that here was the basis of the airscrew.

When Sir George Cayley stated that he saw no reason why aerial transport at speeds of between twenty and 100 miles per hour with a load of passengers or goods should not eventually become easier than carriage on water, his views were, of course, dismissed as those of a cranky visionary. But he persisted in his work, and made a glider of considerable size which may have carried a human being, but seems mainly to have been used for experiments without a passenger. His main problem was power, and though he investigated the possibilities of the steam engine he saw that it was far too heavy. In his writings he envisaged a gas engine which, in fact, was basically the internal combustion engine which made powered flight possible a century later.

If Sir George Cayley had concentrated on gliding flight instead of searching for a power unit, it may well have been that the science of aeronautics would have been advanced by fifty years or more. As it was, his work contained virtually all the principles of the aeroplane of the early twentieth century, and if its pioneers had acquainted themselves with Cayley's work they would have been saved a tremendous amount of experiment and trial-and-error building.

Cayley's work gained at least an ephemeral fame. Unfortunately, the main result was to encourage enthusiasm for human flight rather than a careful study of the principles he put forward. And so Englishmen probed the problem in various—and sometimes impracticable—ways. Thomas Walker, a young man of twenty-five at the time, published a treatise on *The Art of Flying by Mechanical Means* in which wings made of whalebone and wood would flap in imitation of a bird. Some twenty years later he revised his work and suggested two fixed wings and two flapping ones. The theories were both unworkable, and neither model seems to have been constructed.

More interesting is the work of William Henson and John Stringfellow, who actually patented an aerial steam carriage in 1842. The registration of such a patent aroused great interest, particularly in the Press, and engravings of the machine soaring above admiring crowds appeared in many magazines of the time. Both the men were engineers, and the proof that they had attacked the problem from the practical viewpoint is shown by the specifications of their patent. The design is remarkably similar to the flying machines prior to the First World War. "Aerial", as it was called, was a monoplane with a wing span of 150 feet. Henson's calculations showed that the lifting power was in the nature of 1 lb. per 2 square feet. The power was to come from a steam engine of 20–30 h.p. driving two six-bladed airscrews, set side by side and acting as pushers.

Although there was plenty of talk about the flying machine, the public was not prepared to put any money into it, and a company which was formed, named the Aerial Steam Transit Co., failed because of the absence of more than a handful of shareholders. However, both the engineers persisted with their scheme, and having gained sole control of the firm, they started to make some models. One was quite a large affair, with a 20-foot wing span and a steam engine. It was completed by 1847, and taken to Bala Down, near Chard, Somerset, for trials. Apparently it glided quite well, but powered flight was impossible. The trouble was the weight of the steam engine in relation to the lifting surface area, but Stringfellow put the failure down to the damp day, which spoiled the surface silk of the wings. This attitude of accidental failure through climatic conditions was presumably not shared by Henson, who had spent a lot of his own money in the seven years of work, for he emigrated to America and never made any further experiments. Stringfellow, however, carried on, and made history a year later with the first recorded flight of a power-driven aeroplane. A vivid description of the model was set down in a monograph written by his son, F. J. Stringfellow, in 1892. It is a historic document, though not so regarded when published, and the fact that this model actually flew despite the weight of a steam engine for motive power must impress model aircraft enthusiasts to-day who have tiny diesel engines and jet apparatus at their disposal. The relevant details from the monograph are as follows :

> My father had constructed another small model, which was finished early in 1848, and having the loan of a long room in a disused lace factory, early in June the small model was moved there for experiments. The room was about 22 yards long, and from 10 to 12 feet high. The aero-planes of this model were about 10 feet from tip to tip, and 2 feet at the widest part, tapering to a point, slightly curved on the under surface, rigid in front, feathered at the back. Length of tail 3 feet 6 inches, width in the widest part 22 inches, surface in wings and tail about 14 square feet. Right and left screw propellers 16 inches in diameter, with four blades, occupying three-quarters of the area of the circumference, set at an angle of 60 degrees.
>
> The cylinder of engine ¾ inch diameter, length of stroke 2 inches, bevel gear on crankshaft giving three revolutions of propellers to one stroke of engine. The weight of the entire model with water and fuel was under 9 lb. The inclined wire for starting the machine occupied less than half the length of the room, and left space at the end for the machine to clear the floor.
>
> In the first experiment the tail was set at too high an angle, and the machine rose too rapidly on leaving the wire. After going a few yards, it slid back as if coming down on an inclined plane at such an angle that the point of the tail struck the ground and was broken. The tail was repaired, and set at a less angle. The steam was again got up and the machine started down the wire, and upon reaching the point of self-detachment, it gradually rose until it reached the farther end of the room, striking a hole in the canvas placed to stop it.
>
> In experiments the machine flew well, when rising as much as one in seven. The late J. Riste, Esq., lace manufacturer, Northcote Spicer, Esq., J. Toms, Esq., and others, witnessed experiments. Mr. Marriott, late of *San*

> *Francisco News Letter*, brought down from London Mr. Ellis, the then lessee of Cremorne Gardens, Mr. Partridge, and Lieutenant Gale, the aeronaut, to witness experiments. Mr. Ellis offered to construct a covered way at Cremorne for experiments. Mr. Stringfellow repaired to Cremorne, but not much better accommodations than he had at home were provided, owing to unfulfilled engagement as to room. Mr. Stringfellow was prepared for departure, when a party of gentlemen unconnected with the gardens begged to see an experiment, and finding them able to appreciate his endeavours, he got up steam and started the model down the wire. When it arrived at the spot where it should leave the wire, it appeared to meet with some obstruction, and threatened to come to the ground, but it soon recovered itself, and darted off in as fair a flight as it was possible to make, to a distance of about 40 yards, where it was stopped by the canvas.
>
> Having now demonstrated the practicability of making a steam engine fly, and finding nothing but pecuniary loss and little honour, this experimenter rested for a long time, satisfied with what he had effected. The subject, however, had to him special charms, and he still contemplated the renewal of his experiments.

Like his erstwhile colleague, Benson, Stringfellow had little to show in the way of monetary reward for all his years of work. He was at this time fifty years of age, and for the next eighteen years he seems to have abandoned his experiments. When the Aeronautical Society of Great Britain was founded under the Presidency of the Duke of Argyll in 1866, he once again started work on models, completing a triplane which weighed only 12 lb. complete with a steam power unit. This he exhibited, together with some model steam engines, at the first aeronautical exhibition held at the Crystal Palace in 1868. He won a prize of £100 for the lightest engine in proportion to power on show. Stringfellow was by now, of course, an old man. He lived another fifteen years, dying in 1883 at the age of eighty-four just a little too soon to know that the problem of the power unit had been overcome.

In the latter half of the nineteenth century the conquest of the air occupied the attention of inventors the world over. They were busy in France, America, and Australia. In Britain Thomas Moy exhibited the Aerial Steamer at the Crystal Palace show of 1875, which, placed on a circular railway track, rose a few inches when moved forward by its twin propellers geared to a 3 h.p. steam engine. But the real progress was coming in gliding flight where the bugbear of engine weight did not dash all hopes. Inspiration came mostly from the German inventor, Otto Lilienthal, whose successes particularly impressed Percy Sinclair Pilcher, a lecturer in engineering at Glasgow University. Pilcher made many successful flights of twenty seconds or so from the hills along the banks of the Clyde around Cardross in 1895. A year later at Eynsford, Kent, he constructed a new glider called the Hawk which regularly flew 200 yards and more. Pilcher believed it to be capable of supporting the weight of an engine, and this was under construction when he was killed while gliding at Stanford Hall, Market Harborough, in September 1899. Six years earlier than this a pilotless machine equipped with a steam engine, built by Horatio Phillips, had risen a few feet when tested at Harrow, Middlesex. Very much more powerful was the flying machine built by Sir Hiram Maxim and tested on a special track at Baldwin's Park, Kent. It was constructed of metal tubes and was so placed on the rails that it could not rise more than 2 feet, the object being mainly the study of airscrews and aerofoils. Its two engines could develop 180 h.p. under full pressure of steam. The flying machine, in the three tests made, did actually leave the ground, in the last test in 1894 pulling partially free from the tethering mechanism and damaging the track. Steam was not shut off before the machine sank and was partially wrecked by its endeavour to rise. Maxim calculated that the total lift in this test had been 10,000 lb. On such power the machine would have been capable of free flight, though probably an uncontrolled one, with more disastrous results than actually happened.

The race to conquer the air with heavier-than-air machines so well begun in Britain was now nearly over. On a bitterly cold December day in 1903 near Kitty Hawk in Dare County, North Carolina, the brothers Orville and Wilbur Wright made four flights. Their machine was powered by a petrol-fired internal combustion engine (of 12 h.p.), and one may well feel that if it had not been for the reactionary legislation which had prevented British inventors from developing this type of power unit for road transport the hundred years of pioneer work on aeronautics which stood to the credit of British engineering science might have brought a different chapter in the story of aviation development.

Although nine out of ten people who read the brief reports in the press of the Kitty Hawk experiments disbelieved them, engineers the world over redoubled their energies, and simultaneous improvements and additions to knowledge were reported from every large country. In this work France led the field. The first Briton to fly in this country was Colonel J. T. C. Moore-Brabazon (now Lord Brabazon), who flew in a Voisin (French) biplane at Leysdown, Isle of Sheppey, in May 1909. Previous to this, S. F. Cody, an American working in England, had demonstrated his " power kite " to the War Office at Farnborough, in 1908—the first tiny demonstration of air power to the British armed services, who were, however, even then using balloons.

The military accent on the aeroplane (the Wright Brothers had considered this the aircraft's principal, if not sole, useful activity) eclipsed any other at this time. The swept-wing, tailless aircraft exemplified in the Fairey F.D.1 jet fighter, was already in the mind of one British aviation scientist., J. W. Dunne, who at the age of twenty-five showed brilliant promise far ahead of his time in the visionary concept he had of copying the simplest design of flying objects in Nature.

Dunne's first interest was in rotor aeroplanes, but in 1904 he abandoned this field for a study of surfaces which would give stability. He realised that the problem could be equally well studied in paper models as in expensive and unwieldy prototypes, so that his work was hardly spectacular enough to interest the public. In any event it was largely secret, as the War Office was interested. In 1906 he was commissioned to build a biplane, and in the following two years it was completed and tested secretly at Blair Athol, with what success (beyond the ability to leave the ground under its own power) is not discoverable. Dunne died in 1949, and he must have found satisfaction in living long enough to see his design of back-swept wing surfaces and no tail (the basic pattern of sea birds' flying mechanism) being adopted by his successors in the construction of aircraft to pierce the barrier of the speed of sound above 650 miles per hour.

By the vintage year of aeronautics, 1909, many names still familiar in the modern aircraft world were achieving success. The first mile to be flow by an all-British aeroplane was at Shellbeach, when Colonel Moore-Brabazon flew a circular flight on 30 October 1909 in a machine built by Horace and Eustace Short, balloon manufacturers, who had opened an aircraft factory and had secured the right to build machines of the Wright design as well as making those of their own invention.

This machine had a 60-h.p. engine, but earlier that summer a machine with only a 9-h.p. engine had been built by Sir Elliott Vardon Roe and successfully flown by him on Lea Marshes. The Avro which followed in 1912—known as the model 504—was undoubtedly the most efficient and most popular machine produced at that time, and so perfect was its design that it remained basically unchanged (except for the engine unit) for some fifteen years. This machine, with the monoplane produced by F. Handley Page a year earlier, was the foundation of the British aircraft industry, as well as our chief weapon, along with the B.E.2 constructed by Geoffrey de Haviland and E. T. Busk, for Government production in the First World War. T. O. M. Sopwith produced a tractor biplane in 1913 which was a high-speed machine (80 m.p.h. with full load) and the great firm of Vickers started aircraft construction in 1911. Their Vickers Vimy bomber completed the first direct transatlantic flight on 14–15 June 1919, piloted by John Alcock and Arthur Whitten-Brown between St. John's, Newfoundland, and Clifden, County Galway, Ireland.

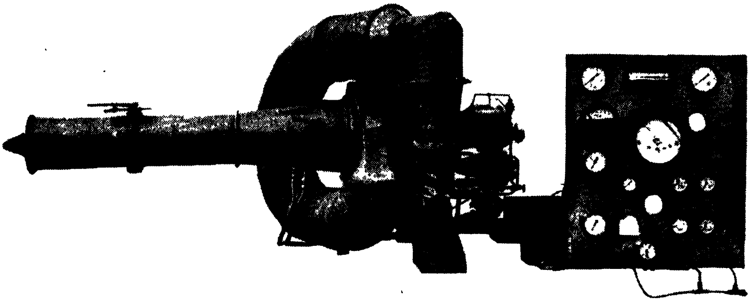
90 Sir Frank Whittle, inventor of the gas turbine for jet propulsion.

Undoubtedly Britain's greatest practical contribution to modern aeronautics came with the historic flight of a jet-propelled aircraft in May 1941, an event heralding a new phase in flying.

Jet propulsion is the most direct means of converting chemical energy into motion, and the earliest steam engine, that of Hero of Alexandria, was constructed on this plan some 2,000 years ago. Nature uses the same method of propulsion in the case of the octopus and the cuttlefish. Newton saw the possibilities of jet propulsion when he propounded his Law of Motion that action and reaction are equal and opposite.

It is possible that the Germans flew a jet-propelled aircraft before the war, but it was presumably a failure. The historic pioneer flight of a successful jet aircraft is undoubtedly that of the Gloster machine in 1941, the culmination of years of work by Sir Frank Whittle. Born in 1909 in Coventry, Whittle applied for admission to the R.A.F. apprentice school at the age of fifteen. He passed his written examination, but was rejected at the physical examination as being too short, too small, and too puny. Undaunted by this, Whittle got in touch with a physical-culture specialist and, with a series of body-building exercises and a special diet (" which consisted mostly of olive oil ", the inventor recalls), he managed to put on 3 inches to his height and 3 inches to his chest measurement. Entry to the apprentice side of the Royal Air Force is always difficult, and there is only one chance. Whittle applied a second time, omitting to mention his previous failure, and relied on the filing system failing to show the duplicate application until he was in. His luck held. He passed all the examinations, and his previous application did not turn up.

After the usual three years as a technical apprentice, Whittle entered an examination for a cadetship. He was one of the six out of 600 entrants who passed. At the age of twenty-one he graduated as a flight cadet, and the thesis he wrote for it, on " The Future Development of Aircraft ", discussed jet propulsion. His examiners, though doubtless amused by the preposterous and visionary imaginings he set down, saw that



91 The prototype Whittle-B.T.-H. jet engine which passed its tests in 1937 —four years before the first jet aircraft flew.

he had a sound technical knowledge and a love of aeroplanes which were the makings of a good technical officer.

Eighteen months afterwards he had drawn his first plans of a gas turbine for jet propulsion, and applied for a patent. Neither the Air Ministry nor private firms would look at the idea. For five years he continued with his designs, but financial backing for production seemed so unlikely that he allowed the original patent to lapse.

Whittle was in very much the same position as the early steam-engine inventors. Manufacturers were not so foolish as to be unable to see the theoretical possibilities of the Whittle engine. They knew that the alloys needed for it did not exist. Just as in the eighteenth century Newcomen and Watt failed to make their early engines efficient because no one could build their boilers and cylinders, there being no demand for such work, so Whittle had to wait for the alloys when the gas turbine had been developed, and it could not be developed until the alloys were available !

In 1935 Whittle received practical help which was the turning-point. Two ex-R.A.F. officers, R. D. Williams and J. C. B. Tinling, helped the inventor to raise the modest capital of £2,000. A year later Flight-Lieutenant Whittle, as he then was, approached the firm of British Thomson-Houston, who for some years had been building steam turbines working at very high temperatures. Their metallurgists had produced alloys capable of withstanding the " cherry red " heat of high-temperature work for prolonged periods. The B.T.-H. engineers considered that an engine of the type suggested by Whittle had a very good chance of successful development. In 1937 the first experimental jet—the " WU "—was completed and tested. A modified engine proved so satisfactory that in 1939 B.T.-H. began production of an engine for flight purposes. This was designated the " WI " and made the first jet-propulsion flight two years later. This engine can now be seen in the Science Museum, while a sister model has been placed in the Smithsonian Institution at Washington.

Sir Frank Whittle is the man who has torn down the barrier preventing high speeds in the air. No matter how fast an aircraft propeller turned, it could not drag the machine through the air faster than the air streamed away from the whirling blades—a theoretical maximum of about 760 m.p.h. at sea-level and a practical maximum far lower. The jet can force gases from its body at infinitely greater speeds. In theory petrol and air will give a speed of 4,800 m.p.h., and other chemicals, such as liquid hydrogen and liquid oxygen, 11,600 m.p.h. There are, of course, enormous problems of streamlining, the concussion of sound waves, and the effect of such speeds on the human brain and body with which to reckon, but the motive power to make them possible is here—ever since the day when a jet plane streaked across the sky of England on a summer's day in 1941.

IV

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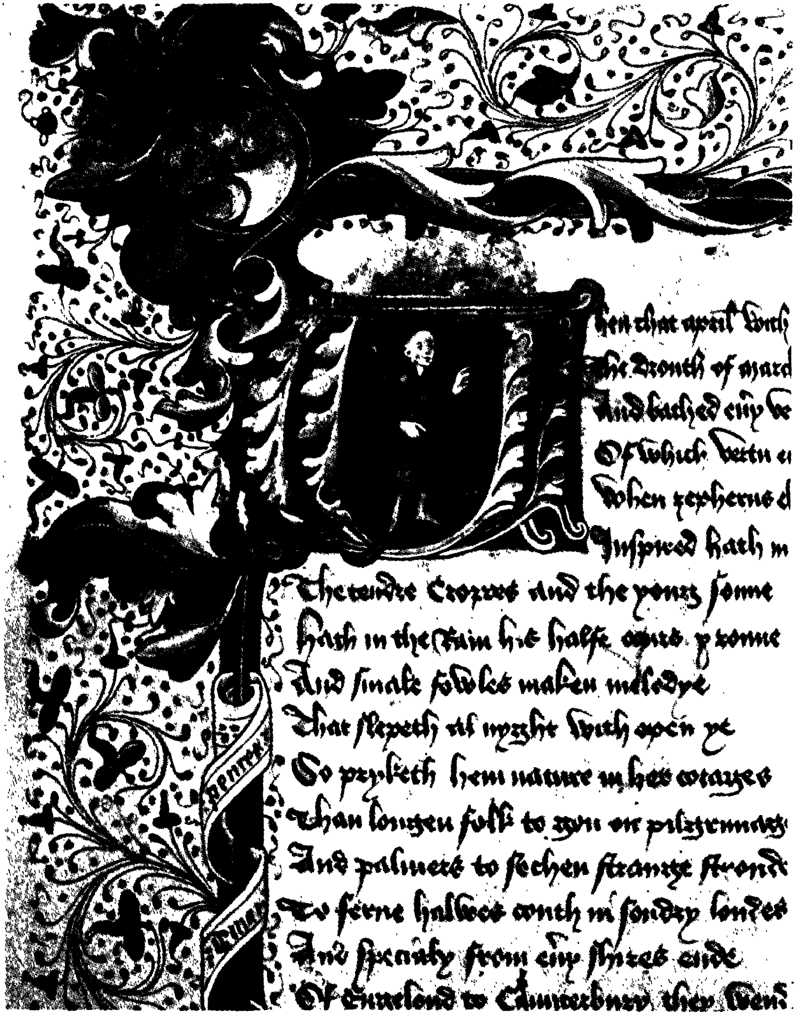


92 Beautiful—but rare and expensive : a hand-produced page from the Prologue to *The Canterbury Tales.*

20

THE PRINTED WORD

CAXTON'S HERITAGE

WHEN a boy named William Caxton came home from school in the Tenterden district of Kent about 1430 he was the admiration of his playmates, for he could read. Children in rural communities of the fifteenth century who went to school were persons of note. For the whole of his life Caxton used to pray for his parents, because they had sent him to school. The prayers were deserved from many more than the Caxtons' son, for the fact that Caxton was literate and a lover of the works of the knight of his native shire of Kent, Geoffrey Chaucer, who had died some twenty years before Caxton was born, was to change history. Chaucer did more than any man to make the English people proud of their new language. In the case of the ordinary people, Anglo-Saxon and a mass of dialects were the normal language. For the governing classes Norman French was both fashionable and official. Geoffrey Chaucer showed that English was capable of expressing every shade of meaning. Caxton came later to build on the foundation which Chaucer had laid and make it the language one day to be used by hundreds of millions of people.

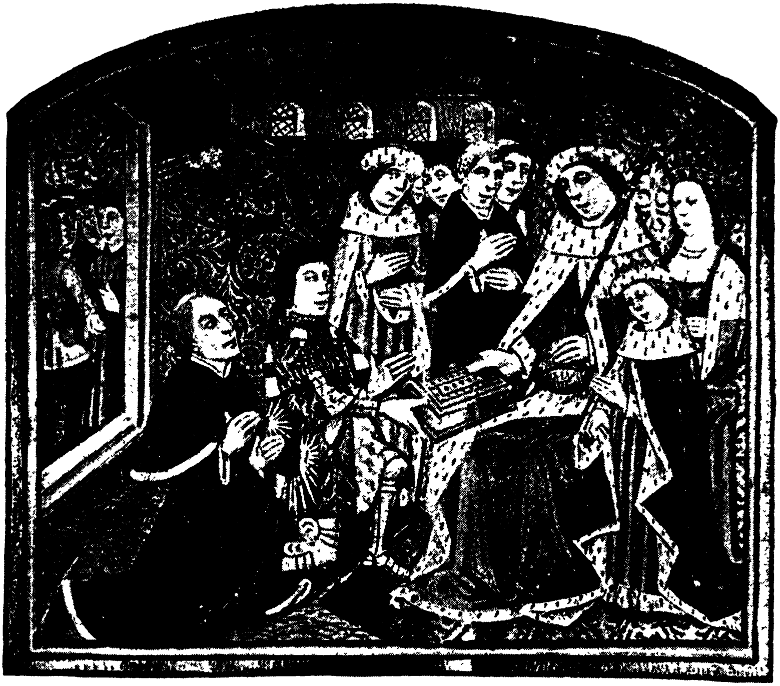
The industry and art of printing which Caxton was to bring to England arrived late in the land. It was flourishing in Europe when Caxton was still in his twenties. The first book was printed about 1445 by Gutenburg, who invented the art, so far as Europe is concerned, at Mainz and Strasbourg. But Europe was also tardy in her discovery. Paper, the essential medium for printing, had been made, in imitating the process of wasps, by China in the first century A.D. and both silk and paper were being printed there with impressed blocks a few years later. Movable types were tried at least a century before

Gutenburg, to reproduce words by Chinese craftsmen. They were impracticable, for the simple reason that Chinese writing needed many thousands of characters against the twenty-six which Gutenburg could use.

Just as the Chinese printers were restricted by their country's method of writing, the European printers could not make printing a servant of the mass of the people because religious authorities had no desire that literacy should extend beyond the priestly caste. The same theoretical restrictions applied in England, but that love of freedom which seems an essential ingredient of the English character saw to it that the new invention should be untrammelled by any religious or political restrictions. Englishmen had to fight for this right as soon as the first printed material appeared ; they have had to go on fighting ever since, and they have always won. Printing slowly brought about the desire for literacy by the nation, and paved the way for a population which was able to carry on technical work. How priceless this inheritance was when Britain became an industrial country a little thought will soon show.

When Caxton was a boy such literacy was an exception. Various sorts of home-made signs served to ensure that people could perform their daily work. Sailors had charts which combined pictures and signs indicating currents, rocks, and routes. Farmers used measurement signs of various kinds. Inns and shops amplified their signs by various simple hieroglyphs to indicate prices and services. The country was, indeed, rapidly developing to a pitch of civilisation where at least the rudiments of literacy were an asset to living. For those engaged in commerce they were, of course, essential.

Caxton's ability to read and write enabled him to obtain an apprenticeship with a wealthy mercer in London, Robert Large, who later became the city's Lord Mayor. Large sent Caxton to Bruges in 1446 as agent for the Mercers' Company. This company was at that time in control of the Company of Merchant Adventurers' activities in the Low Countries, and Caxton was to all intents and purposes empowered with diplomatic status. The job was a very good one, and Caxton earned a considerable income, as is shown from the fact that when



93 Earl Rivers presents a copy of his book, an English translation of *Recueil des Histoires de Troyes*, to Edward IV. Caxton kneels in left foreground.

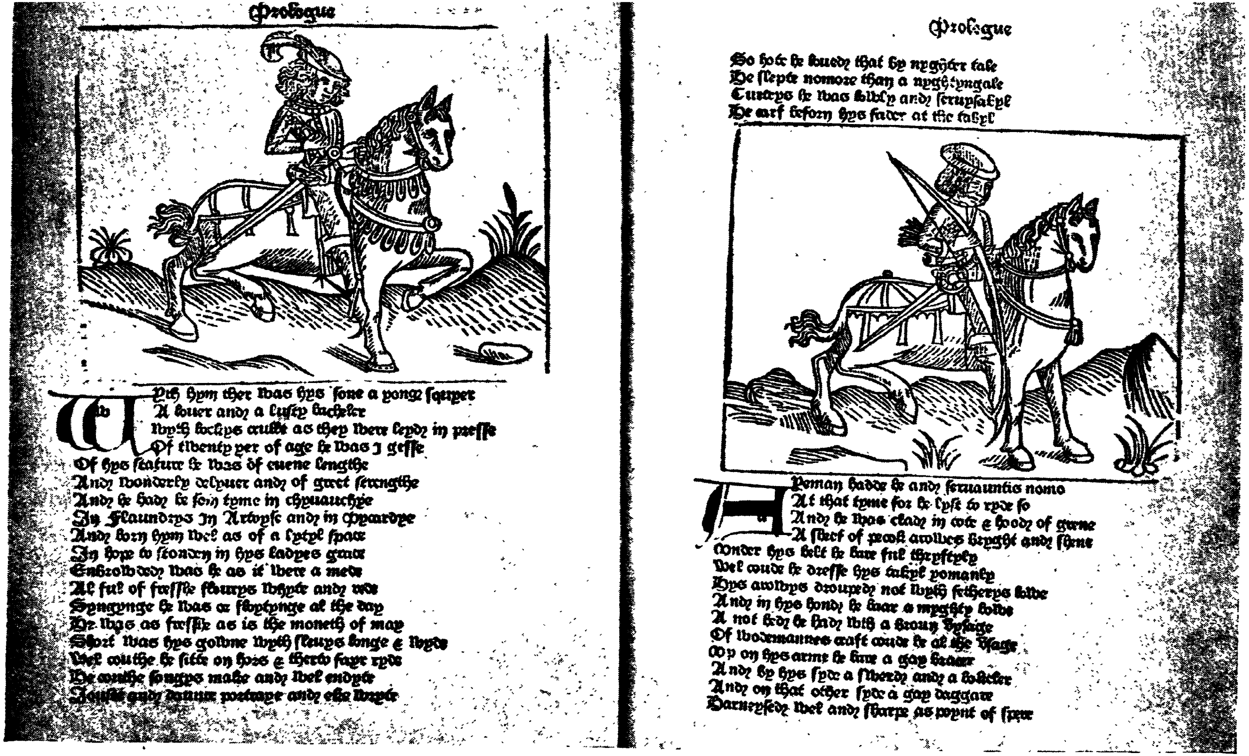
he was thirty he stood security for another merchant in the sum of £110, representing at least twenty times that figure in modern currency. Caxton stayed in Bruges for thirty years. During that time the printing office at Mainz was sacked, and the craftsmen who worked in it fled to neighbouring countries. Caxton, who became fascinated with the new art of printing, seems to have abandoned most of his official work for literary pursuits. With the encouragement of an official friend, Margaret, Duchess of Burgundy (sister of Edward IV), Caxton began in March 1469 a translation of *Recueil des Histoires de Troyes* into English. He completed the work in 1471, and then, either at Cologne or Bruges, in partnership with Colard Mansion, he set it up in type, the first book ever printed in our language.

Although he was more than fifty years of age, Caxton then decided to embark on a new career. Returning to England in 1476, he set up a printing press in or near one of the almshouses of the Abbey of Westminster, under the patronage of the Abbot. The building stood west of the Abbey, between the present Victoria Street and Tothill Street. Although the branches of the printing trade unions of to-day commemorate the Caxton printing works by calling themselves chapels, it is not actually true that Caxton's press was established within the precincts of the Abbey on sacred ground.

With a red pole as his sign, Caxton started work. He had to translate the books as well as print them. A short work on Jason's travels came first, and then in 1477, the *Dictes or Sayengis of the Philosophers.* Between that publication and his death in 1491, Caxton printed over 100 books, using eight type faces and many woodcut illustrations. It need hardly be said that one of the books was the works of Chaucer, the writer who had inspired him more than sixty years before.

His printing press was carried on by one of his assistants, Wynkyn de Worde, who had come over from France to help Caxton. Wynkyn de Worde removed the press to the " Sygne of the Sone, Fletestrete ", (the site was just beyond the city walls at Ludgate, at the foot of Shoe Lane), and so began the connection of that area with the Fourth Estate. One notable fact about Wynkyn de Worde's books was that by 1495 he was using English-made paper. It came from a mill belonging to John Tate the Younger, of Hertford. The demand for paper by the new craft was a valuable stimulus to engineering, and water-mills to provide the power for maceration of the raw materials (rags and fibre) were at that time being built all over Europe.

Other craftsmen, both Englishmen and European friends of Caxton, began to set up printing presses in England. Notable among them was Richard Pynson, a Frenchman who had two presses at Holborn and Fleet Bridge, and who issued the first book in Roman face type in 1509. He also used metal type (in the form of his trademark). In 1510 he was appointed King's Printer, and produced more than 400 editions, many of great clarity and beauty, and including illustrations by Holbein. Within a century printed book material was plentiful



Prologue

With hym ther was hys ſone a yonge ſquyer
A louer and a luſty bacheler
Wyth lockys crulle as they were leyd in preſſe
Of twenty yer of age he was I geſſe
Of hys ſtature he was of euene lengthe
And wonderly delyuer and of greet ſtrengthe
And he had be ſom tyme in chyuauchye
In Flaundrys In Artoyſe and in Pycardye
And born hym wel as of a lytyl ſpace
In hope to ſtonden in hys ladyes grace
Enbrowded was he as it were a mede
Al ful of freſſhe flourys whyte and rede
Syngynge he was or floytynge al the day
He was as freſſhe as is the moneth of may
Short was hys gowne wyth ſleuys longe & wyde
Wel couthe he ſitte on hors & therto fayr ryde
He couthe ſongys make and wel endyte
Iouſte and daunce portraye and eke wryte

Prologue

So hote he loued that by nyghter tale
He ſlepte nomore than a nyghtyngale
Curteys he was lowly and ſeruyſable
He carf before hys fader at the tabyl

Yeman hadde he and ſeruauntis nomo
At that tyme for hym lyſt to ryde ſo
And he was clad in cote & hood of grene
A ſheef of pecok arowes bryght and ſhene
Vnder hys belt he bare ful thryftyly
Wel coude he dreſſe hys takyl yomanly
Hys arowys drouped not wyth fetherys lowe
And in hys hond he bare a myghty bowe
A not hed he had with a broun vyſage
Of wodemannes craft coude he al the vſage
Vp on hys arme he bare a gay bracer
And by hys ſyde a ſwerd and a bokeler
And on that other ſyde a gay daggare
Harneyſed wel and ſharpe as poynt of ſpere

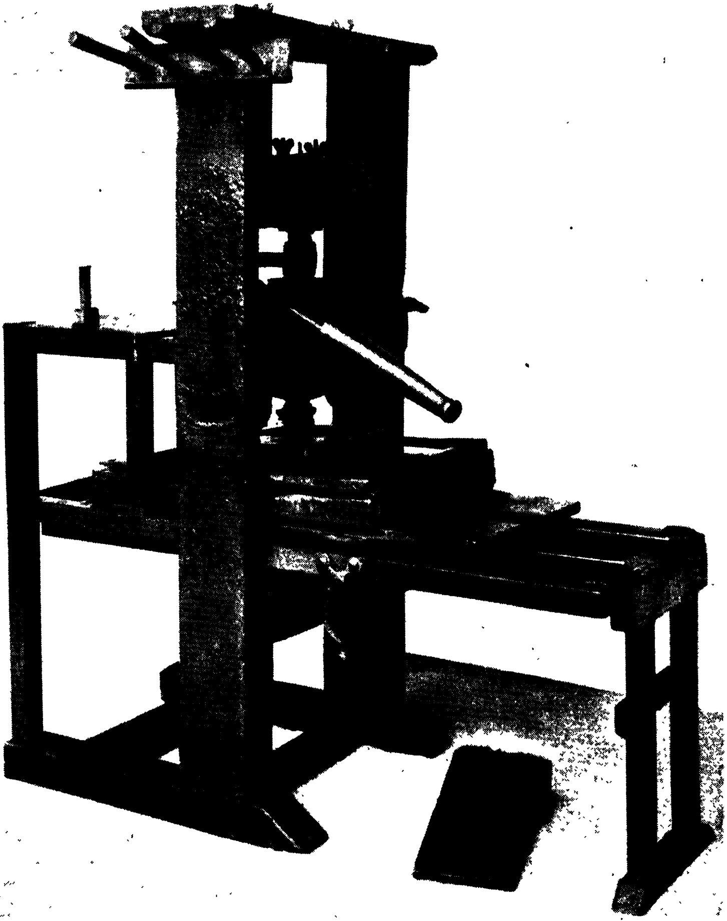
94 Legible, cheap, and plentiful printed pages from Caxton's edition of Chaucer's *Canterbury Tales*.

and cheap. Authorship became a lucrative profession. It is not a coincidence that the advent of the new industry coincided with the golden age of English literature, giving this country a timeless fame recognised by the whole world in the works of Shakespeare, Raleigh, and Spencer, all set down in print.

It is sad, therefore, to record that in the seventeenth century both the art and the prosperity of the industry declined. Restrictions under the Commonwealth were one reason, and under Charles II and James II things were little better. Type and paper of quality came from Holland, and few artists saw any attraction in the industry. This situation was materially changed when William Caslon, noting the growth in the number of books, newspapers, and pamphlets which were published after Parliament refused to extend the Licensing Acts which were virtually a Press censorship in 1694, started a type foundry and in 1720 produced the type which bears his name and is still one of the most beautiful faces among the many hundreds in use to-day.

William Caslon was born at Cradley, Shropshire, in 1692, and served his apprenticeship at a gunsmith's, where he showed that he had a great talent for the intricate engraving then (as now) a feature of gunstocks. He came to London like many another lad to seek his fame and fortune. Some punches for bookbinders' characters which he had produced so impressed two master printers, William Bowyer and John Watts, that they set Caslon up in a foundry in an alley off Old Street in the City. The Caslon Old Face brought a renaissance to the English printing craft, and the period 1770–1820, during which another English type, Baskerville, was also designed, is one of the greatest of the industry's history so far as art is concerned.

Production costs were still so high that printing for the masses remained a dream. Paper was hand-made, type hand-set, and presses hand-operated. The machines of the Industrial Revolution had to be harnessed to cheapen production. Baskerville had invented the method of making woven paper because he wanted something which would take a firm and even impression to show off the thick and thin strokes of his type to the best advantage.



95 An early printing press of the type that Caxton used.

Then a Frenchman named Didot brought his design for a paper-making machine to be run by steam power to England in 1803. This poured the wet pulp on to an endless belt of wire mesh through which the water drained. The machine could produce five or six miles of paper a day. It was the first major step in the improvement of print production for nearly 400 years.

Not every printer was pleased at the mechanisation of his craft. Many considered it would cheapen the art. The reason for this is that most printing concerns were very small indeed, and run as a subsidiary department of a bookselling business. The majority of them were in London, and as diaries and stories of authors of the time show, most of them had two or three hack writers, and maybe an author of repute as well, to write material for them. Several of the big printing firms of to-day can trace their origin to these early years of the nineteenth century, and records still kept show how little changed the printing shop was from that of Caxton in the Abbey Almonry. The proprietor worked with three or four assistants in a back room or cellar. Work went on from seven or eight in the morning till seven or eight at night, and the only holidays were Christmas and Sundays. But the compositors were quite well paid by the standards of the time, and they regarded themselves as superior to other workers, which is why they wore paper caps, the badge of the skilled artisan, in contrast to the hard hat and breeches of the general labourer.

Piecework rates were universal, enabling a man to earn about 30*s*. a week when fully employed. There was a general practice of charging three times the rate on ordinary work for " fine work "—significant evidence of the poor quality of the routine job. This was due not so much to the workers' inefficiency as the inferior material. Type was usually scarce and battered. The " donkey ", as the compositor was called (the pressman's nickname was " pig "), could always show evidence of his calling by the scars on his hands, caused when he cut display letters from a block of wood because there was none in the racks.

Compositors were envied by other workers, and not only for their comparatively good wages, but because they were literate. At the end of the eighteenth century the increase in child labour and the collection of large numbers of people in towns had hindered the very commendable progress in education made since Tudor times.

In England's population of 9 millions of the year 1800 it has been estimated that only one adult in eight was literate. Few families had more than a Bible, one or two bound books, such as *The Pilgrim's Progress* and similar religious works, and a few pamphlets.

A newspaper was a rarity, though the influence of the Press was out of all proportion to the circulation. The French Revolution, the secession of the American colonies, and the ever-present threat of attack by Napoleon had created an awareness of the world beyond the village or provincial town almost for the first time in the nation's history. The hunger for print was there, and not even Pitt's heavy Stamp Duties, which restricted leading newspapers like the *Morning Post* to a circulation of not more than 1,000 copies a day for a four-page issue costing 6*d*., could curb the growing demand for information.

Germany was the first nation to invent a steam press. The invention of Frederick Konig, its successful use was in England. On 29 November 1814, John Walters, the proprietor of *The Times*, watched the first copies come off a machine powered by steam and using curved matrices on a cylinder.

Mechanical typesetters, produced in Germany and America, came in the latter part of the century to free the industry from its last delaying shackles. It will be seen that British inventiveness has not made an outstanding contribution to the progress of print, but consistently, from the time of Caxton to the present day of the largest newspaper circulations of any country, this nation has been to the fore in the development and practical use of print. The reason that printers could do so was that the population was ready and eager to read. The man who made it possible may have only an indirect connection with our industrial progress, but his contribution is surely worthy of mention. He was Edward Edwards, father of the public library. The son of a Whitechapel bricklayer, he was himself working long hours on house-construction in 1824, when he was fourteen. How he managed to find the time and ability to make himself a highly cultured and educated man one can only marvel at, but by reading at the British Museum and attending classes at a Mechanics' Institute he managed, by the time he was twenty-four, to become an authority on the educational possibilities of private reading, and in 1836 he was on the staff of the British Museum. Edwards found a friend and helper in his aim to make books available for the "common people" in William Ewart (after whom Gladstone was named), the son of a Liverpool merchant. A scholar of Eton and Christ Church, he entered Parliament in 1828 and started a correspondence with Edwards on industrial design, art, and books. The result was the setting-up of a Parliamentary Select Committee in 1849 under the Chairmanship of Ewart, who adroitly called as chief witness Edwards, and the latter's friends as the informants. From this action emerged the Public Libraries Act of 1850, which empowered towns with a population exceeding 10,000 to levy a rate for running and housing libraries. Five years later the qualifying population figure was reduced to 5,000 and the Act permitted books to be bought.

The hunger of the industrial population for books could now be assuaged. Even before this Warrington and Salford were running municipal libraries, and by 1852 they were open in Bolton, Liverpool, Manchester, Oxford, Norwich and Winchester.

Edwards died at Niton, Isle of Wight, in 1886. By then nearly 10 million books were being issued free every year. A love of reading became universal. People borrowed books and bought books. Periodicals and newspapers flourished. The most literate and print-conscious people in the world were bringing prosperity to an industry which to-day gives employment to nearly half a million men and women. The cheaply- or freely-available printed word was like a torch illuminating the dark recesses of the land. No longer was literature a luxury for the well-to-do, but a popular pastime and universal means of self-education. The symbolic destruction of darkness was, appropriately enough, accompanied by great advances in the devices for providing artificial light.

96 Books for the million as a right of citizenship : the young people's section of a modern public library.

21

VICTORY OVER DARKNESS

DEVICES FOR ARTIFICIAL ILLUMINATION

WILLIAM Murdock's discovery of coal-gas was the first important step forward in improving artificial illumination. But the real function of gas is the production of power and heat, its primary use to-day. The electric lamp was the device which made manufacturing entirely independent of daylight, and the upward curve of the lamp's efficiency was reflected in the increased output from factories, with night shifts as well as winter work before and after the short hours of daylight.

The brightness obtainable from an arc discharge of electric current in air or an imperfect vacuum was known early in the eighteenth century. Hauksbee, about whom very little is known (he died in 1713), noted a glow discharge when using a friction electric machine during experiments in 1709, when he was investigating insulators and conductors of electricity, and it was envisaged that this might be a method of providing artificial light. A step forward came when Sir Humphry Davy demonstrated the carbon arc at the Royal Institution in 1810. This scientist, whose work would justify his inclusion in many other sections of this book, is popularly best known for his Davy miner's lamp, though that was not so revolutionary as his carbon arc. Davy was born at Penzance in 1776, the son of a master carpenter. The schools of the West Country, at that time a prosperous tin-mining area, gave Davy a fine education, but his early scientific training was a labour of love for an old Quaker named Robert Dunkin, whose work as a saddler was almost a sideline to his experiments with electricity in the attic of his house. Later Davy gained the friendship of Gregory Watt, son of James Watt (the steam engines of Boulton and Watt found a ready market in the mines

97 Only on occasional feast days could candles be used in lavish numbers like this: bringing in the Yule Log.

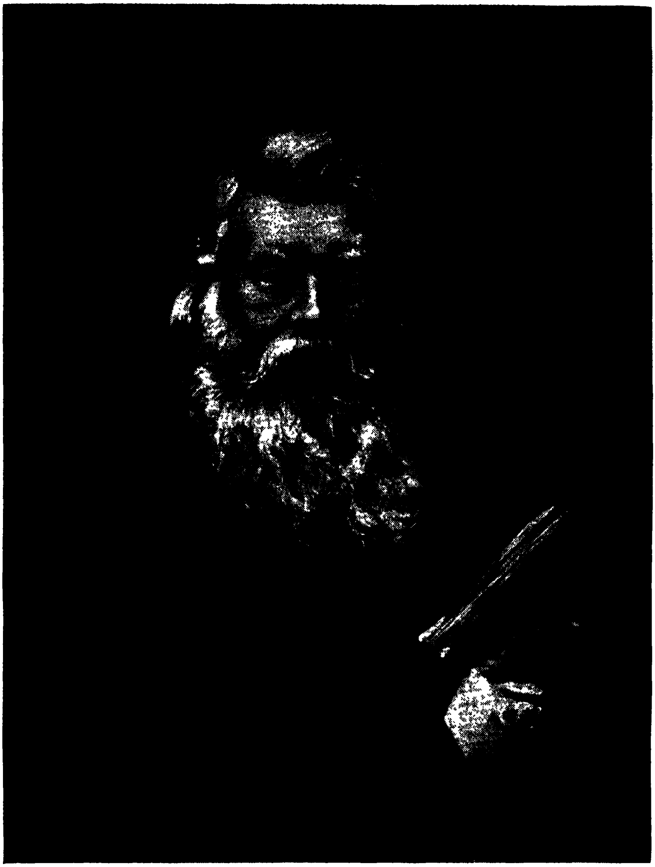
of Cornwall), and as a result a proper training in chemistry and metallurgy was provided for the youngster. For a time he worked in a medical clinic at Bristol, and here he experimented with laughing gas and other gases, which had the direct result of an offer of an assistant lectureship at the Royal Institution when he was only twenty-three.

The charm with which he gave his lectures before the members of that august body, almost as much as the importance of his discoveries, made him one of London's social lions. Davy travelled extensively to the universities of Europe, and he later withdrew from active work, married a rich widow, and died at Geneva in 1829.

The Davy lamp, which banished some of the dangers of coal-mining, was produced in 1815. Although the placing of a cylinder of wire gauze round the flame of an oil lamp to render it safe in an explosive mixture of fire damp may seem an obvious solution to-day, it was the culmination of long research. The amount of light it provided was not great —about half a candle-power—but it was far better than the pathetically dim illuminants which had to be used prior to the Davy invention. Putrescent fish giving a vague light through phosphorescence was one method. Another was a flint mill in which a boy turned a steel wheel which struck sparks from a flint pressed on the surface. The best light available before the Davy lamp was produced was an oil lamp in which the air for the flame passed through a water seal ; this required a child for continuous pumping. Great as the improvement of light from the Davy lamp was over these lights, it was also of incalculable value in staving off disaster by showing the presence of fire-damp in the changing colour of the flame.

To return to the electric arc light, Davy had made his demonstration with the facilities provided by the Royal Institution in the shape of a very large battery of Voltaic cells. Such a source of supply for continuous illumination was neither feasible nor possible at that time outside the laboratory. It is stated that to produce an arc 4 inches long Davy used 2,000 cells.

Some easier means of controlling the glow caused by the resistance of a conductor to electric current were needed. Many scientists in both Britain and America devoted their energies to the problem, and a boy born in Sunderland in 1828 was one of the two inventors of the first practical electric lamp—Joseph Wilson Swan. His parents were of Scots descent and in comfortable circumstances. Joseph loved to visit the factories near his home, and he spent many hours in the home of a family friend, John Ridley, who experimented with electricity. On leaving school at the age of thirteen, he was apprenticed to a firm of Sunderland druggists, Hudson and Osbaldiston. Owing to the death of both the partners, the apprenticeship came to an abrupt end, and Joseph Swan went to another druggist at Newcastle, John Mawson. At seventeen he began his experiments with the electric filament lamp. He took pieces of paper of various types and after cutting them into strips carbonised



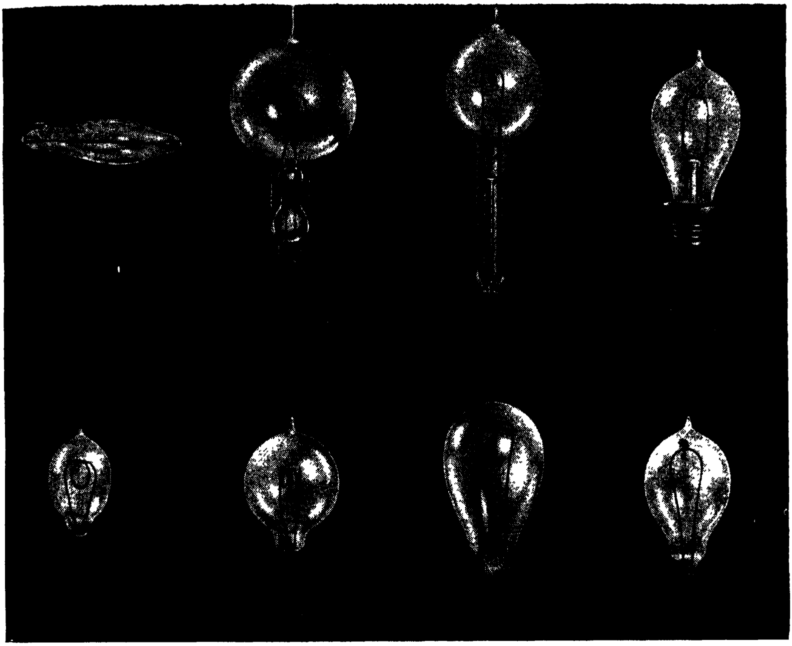
98 Joseph Swan, who spent twenty-seven years on experiments to perfect his electric filament lamp.

them by baking them in powdered charcoal. The experiments continued for some years, and the carbonised strips were tried out in very simple glass containers. A typical one was a glass bottle closed with a rubber stopper, and another was an inverted bell jar. He could not obtain an efficient vacuum in such receptacles, and though he obtained light for brief periods the paper filaments soon broke down.

The years passed, and then in 1865, some twenty years after his first experiments, a more efficient vacuum pump was available. By chance Swan heard of a Birkenhead bank clerk named Charles H. Stearn who, as a hobby, was experimenting with very high vacua. Swan wrote to him, and the result was a working partnership. Disappointment still dogged Swan. The carbon films (they were not called filaments at this time) continually broke when a current was passed through them, and the interior surface of the glass became covered with a black smoke. Swan overcame this major problem by a discovery which is still a fundamental process in lamp manufacture. It was in 1878, though the method was not patented until 1880, that he found that by passing a strong current through the carbonised material while the process of air exhaustion was actually continuing the smoke was drawn out. More than that, the carbon did not then waste away or break.

The first successful lamp burned for a few minutes in a demonstration to the Newcastle Chemical Society on 18 December 1878, and on 17 January 1879, another lamp was exhibited at a lecture in Sunderland. In the next few weeks several demonstrations were given, and then Swan and Stearn returned to their experiments. The most important innovation was the use of " parchmentised thread ", made by mixing sulphuric acid with cotton, for the filament. This was patented in November 1880.

Meantime Thomas Alva Edison, with about 100 assistants, was busy in America pursuing the same objective as Swan. Edison announced in October 1878 that he had successfully tried out a lamp with a filament of platinum wire. The news caused gas shares in England to slump, but with further news that the announcement of success was a little premature they soon rose again. News of Edison's triumphs was announced at regular intervals, and great as the work of that remarkable inventor was, they were very often the figments of imagination of news-hungry reporters. When *Nature* published in December 1879 a report that Edison had perfected a lamp with a paper carbon filament, Swan felt compelled to write to the Editor pointing out that he had used charred paper fifteen years earlier.



99 Six years' progress in lamp manufacture—from Swan's first lamp of 1878 to the single loop filament bulb of 1884.

Swan was doubtful if the general idea of a filament lamp could be patented. The more cautious Stearn felt certain that it could, and he continually begged his partner to protect himself. His apprehensions were well founded, for on 10 November 1879 Edison obtained a British patent on very broad terms for a carbon filament lamp in a vacuum. Actually the first Edison lamps demonstrated in Britain did not have paper carbon filaments, but used carbonised bamboo. There was all the material for a first-class lawsuit, but the two inventors soon took the more sensible course of exploiting their inventions in partnership from 1883 onwards.

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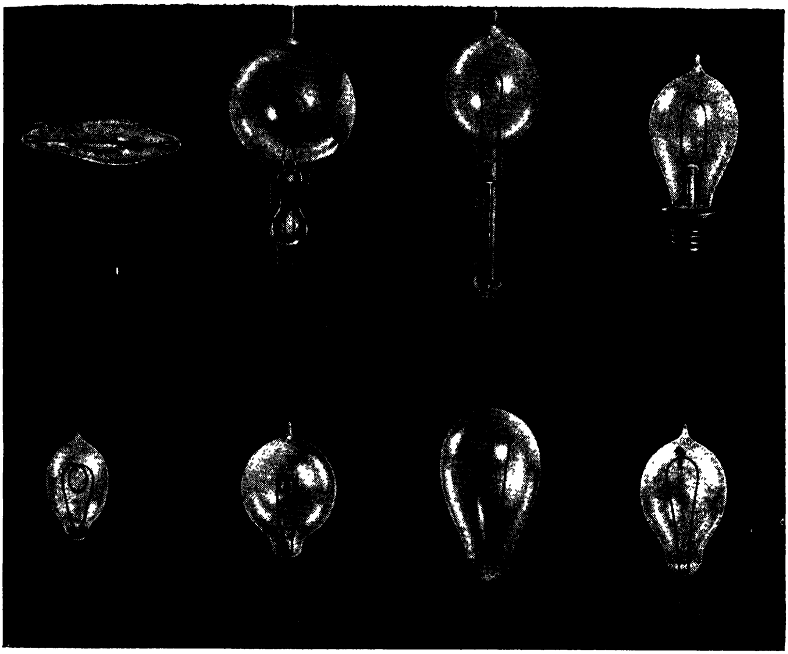

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Before this Swan decided to launch into commercial production. The first large-scale exhibition of the new lamps was given in Newcastle on 20 October 1880, during a lecture. At a given signal the seventy gas jets of the hall were turned off, Swan turned a switch, and twenty electric lamps shone out. The public's interest was captured, and enquiries began to flow in. A factory was started at Benwell, near Newcastle. German glass blowers had to be brought over to assist the only Englishman, Fred Topham, who had the necessary skill for making the bulbs.

In 1883, by which time Swan had moved to Bromley, Kent, he began work on his squirted filament. His method was to force nitro-cellulose through a tiny hole into a coagulating liquid so as to form a homogeneous thread. This thread was washed in ammonium sulphide and then carbonised. The fine uniform thread thus obtained made lamps much more economical and very soon this type of filament became universal. The thread was, of course, a form of artificial silk, and though Swan himself made no attempt to develop the idea for textiles, his wife crocheted some of it into lace, and the work was exhibited in 1885 at an Inventions Exhibition under the description of artificial silk.

Sir Joseph Swan, honoured by learned societies the world over, died at his home at Warlingham, Surrey, in May 1914. During his long life he had seen a dark world of night-time turned into a brilliant scene by the lamps which occupied thirty years of his life to bring to success.

While Swan and Edison were working on the filament lamp many other electricians were using the more reliable and stronger source of electric current to improve the arc lamp. The first important use to which the arc was put was in the South Foreland Lighthouse. A five h.p. engine drove a Holmes generator installed in the base of the lighthouse, and on the night of 8 December 1858 the South Foreland light blazed out with 1,500 candle-power. The crews of vessels moving through the Channel crowded on the decks to see this phenomenal brilliance, and, as a writer of the time said, " fell on their knees and gave thanks to God ". Without doubt this reaction of joy occurred on many ships which passed near the blaze of light from the South Foreland. The increasing tempo of trade was forcing ships' masters to take risks to maintain their schedules, and the toll at night in the treacherous seas between the Thames Estuary and the open Atlantic was terrible.

To contrast the brilliance of the South Foreland arc with the light from other lighthouses, one only needs to realise that the latter's power was very small indeed. Up to 1816 a coal fire supplied the warning beacon on May Isle in the Firth of Forth. Elsewhere candles had been quite usual until the end of the eighteenth century. The Eddystone, for example, showed only the fitful warning glow that two dozen candles would give. The blazing arc in the lighthouses and the feeble glow in the miner's lamp were both originally the products of Davy's brain. On humanitarian considerations alone they should bring him the lasting gratitude of mankind. In comparison, the practical advances which they made possible in the progress of industry and commerce seem almost tawdry —but they were none the less tremendous in their effect. The electric arc yielded to the rapid improvement in the filament lamp. The latter's life history is likely to be far longer because of its cheapness, but in time it will give way to the electric discharge lamp already universal in modern factories and business houses, though its high initial installation cost has so far limited its use in domestic houses.

The phenomenon of luminescence has aroused superstitious fear and scientific interest for many thousands of years because it is so common in Nature. The Japanese knew how to produce luminous paint at least 1,000 years ago, and they gave the secret to China. The same formula was independently discovered by Canton in England in 1768 when he heated oyster shells and flowers of sulphur together to produce calcium sulphide. The Irishman Stokes distinguished the difference between fluorescence and luminescence in 1852, the latter being caused by heat, visible light, or ultra-violet radiation. From then until the present time research has gone on, first of all for scientific knowledge and then for commercial production, on an international basis, with America in the lead. This supremacy culminated in the illumination of the New York World's Fair in 1939 by fluorescent lamps. Restrictions occasioned by the war delayed British manufacture still more, and only now is our progress comparable with that on the other side of the Atlantic.

Britain, has, indeed, been tardy in utilising the benefits of electricity. The supplies of cheap coal and the high cost of early electrical generating equipment were the basic cause more than a mulish obstinacy in recognising the importance of the Davy arc and the Swan lamp. The result of a blundering development, useless competition (there were fifty different systems of supply of electricity in London alone at the end of the First World War) has been seen in the shortage of electric power in recent years. Order out of chaos came when the Central Electricity Board was set up in 1926 and the Grid system distributed electricity on a national basis.

Another defect is Britain's lack of " white coal ", water power, for the production of electricity. Little more than 3 per cent. of our current is generated by hydro-electric generating stations, though vigorous development since the war is adding the equivalent of 1,163,000 h.p. to our resources. Even the wind is being pressed into service, with experimental generators in operation in the Shetland Isles and north–west Wales.

The goal of providing electric light for every workshop and cottage has not yet been reached, but the end of this battle of light over darkness is in sight. Nuclear fission, power stations at the pitheads, and the Severn tidal barrage scheme will, in time, bring cheap and abundant light to everyone.

22

LETTERS FOR EVERYONE

START OF THE PUBLIC POSTAL SERVICE

COMMUNICATION facilities are the nervous system of an industrial civilisation. Without them the laws of supply and demand cannot be promptly obeyed. To-day, when an order for raw materials from a distant part of the country can be made by lifting a telephone or the requirements of a customer on the other side of the world be sent to the British manufacturer in a coded cable for a shilling or two, the difficulties of the early industrialists in Britain in running their communication systems can hardly be envisaged. Flexibility of production was difficult. Quite apart from slow transport of goods, the courier taking any order went almost as slowly. An order from one of the London trade exchanges to a Glasgow cotton-manufacturer would take the best part of a couple of days to reach him, and was a costly communicative process into the bargain.

In the late eighteenth century, when passenger coaches were moving along the roads with a fair turn of speed, the postboys still meandered at the rates set down by Queen Elizabeth of seven miles an hour in summer and five in winter. " Postboy " was an euphemism. Most of them were old, and even the Tudor schedules were regarded as theoretical. John Palmer, who ran the first mail coach in 1784, had a short time previously pointed out that " the Post, instead of being the swiftest is almost the slowest conveyance in the country, and though from the great improvement of our roads, other carriers have proportionately mended their speed the Post is as slow as ever ".

Industrialists found their own solution, even though the commissioning of anyone other than the Post official to carry letters was illegal. Though the employers were able to overcome the deficiencies of the country's official Post Office services by their own resources, such a solution was not usually available to their workers. The enormous numbers of people moving into the towns at the turn of the century was a social revolution in itself. Families which could trace back their connection with a village for centuries were broken up. From the Yorkshire dales, the wild country of the Pennines, and the fields of the Midlands the youngsters tramped in search of work, and maybe fame, to the new industrial towns on the Tyne, in Lancashire, and the Midlands. For all those left behind saw or heard of them they might as well have emigrated to America. Cross-country post services were unreliable, and except in the case of the routes between main centres of population it was likely that a letter would have to go to London and then back again, the charge being on the mileage rate. In the case of the thousands of Irish boys and girls who flocked into Lancashire at this period, the situation was even worse. A letter sent to their families and the ensuing reply cost the equivalent of a day's wages. Poor food, bad working conditions, and low wages were the main causes of the strife which lasted until well into the nineteenth century in the manufacturing areas. An important contributory cause was the feeling of insecurity. Old loyalties had dwindled among these people torn up from roots deep in the soil of their traditional occupation. This feeling of insecurity aggravated conditions which might otherwise have been borne with more patience. Only a few Members of Parliament had the sensitivity to see this, among them Robert Wallace, one of the great crusaders for a cheap postal service.

The insistence of industry upon the institution of a cheap and efficient postal service brought little reaction from the Government. Burdened with heavy costs in the shape of " patents " which a succession of monarchs, notably Charles II, had imposed on it to provide a pleasant income for Court friends, the Post Office had little chance of operating efficiently even if it had desired to do so. There was little evidence that it did. Nepotism was rife, and the centuries-old attitude that

100 Carrying the Royal Mail in Tudor England : a foot post of the early seventeenth century.

the Posts were primarily run for the Government's benefit and carried public mail only as a privilege died hard.]

One man changed the situation in ten years, and in doing so gave the world a communication system which is one of Britain's greatest contributions to the welfare and happiness of modern civilisation. His name was Rowland Hill. He was born at Kidderminster in 1795, the son of a schoolmaster who appears to have applied theories on education far in advance of his time. They resulted in considerable success as regards the prowess of the scholars, but with poor rewards for his personal exchequer. The family was invariably in severe financial straits, particularly when the six children were still young and unable to help with the work. If there was little money, there was plenty of education. Later, when the youngsters could themselves teach, things were better. Rowland Hill was taking a class at the age of twelve. His brothers Mathew, Frederic and Edwin were just as forward, and within a short time another school was opened at Tottenham. Rowland Hill was among the members of the family who went to run it, and in the more enlightened environment of the North London village, which was a residential area for wealthy merchants and members of the professional class at that time, came real success.

Rowland Hill, as a modernist, was not unnaturally a Radical. He grasped the new world which was opening before his eyes as an opportunity for the advancement rather than the exploitation of man. Many visionary schemes took his attention, notably one to send a better type of emigrant to Australia than shiploads of felons. This work, as well as his lively interest in the social changes in Britain, was a reason why he became interested in the postal services. From 1825 to 1835 he made a profound study of the subject and gained the friendship of everyone who was trying to improve it. Among them was Robert Wallace, who, finding an ally, promptly sent him a cabful of documents which he himself had amassed on the subject.

From a study of these, Rowland Hill began his report on the Post Office, being assisted by his brothers in the family's traditional method of tackling problems—a round table conference where everyone could have his say. Rowland Hill realised that facts and figures would be the only way to refute the protests of the Post Office that it was doing the best it could without incurring a loss. By careful calculation, he was able to find that the average cost of distribution of a letter was $1\frac{1}{2}$*d.* This figure was higher than it needed to be because newspapers and enormous numbers of allegedly official letters were carried free. He also analysed the actual cost of carrying a typical letter, one from London to Edinburgh, for which the charge at that time was 1*s.* 1*d.* By estimating the gross weight of the mail coach, and including every overhead cost of vehicle, horses, coachmen, stable hands, and so on, he showed that the letter's share of this expenditure was $\frac{1}{36}$*d.*

101 The Wyon medal, on the design of which the first postage stamp was based: the famous "Penny Black" of 1840.

These two calculations immediately revealed what was wrong with the Post Office. The actual transit costs of a letter were small, but the collection and distributing costs were absurdly high. In fact, the procedure of innumerable clerks examining a letter, weighing it, checking the mileage it had to travel, and then collecting the fee from the addressee was the cause of the prohibitive cost of writing a letter and sending it.

The clue to a modern postal system was obvious from these figures—a flat rate of postage irrespective of distance, and prepayment to obviate clerical and accountancy work. Rowland Hill looked at the charges, which varied from 4*d.* for fifteen miles to 1*s.* 3*d.* for 600 miles, plus extras for carriage over the Menai Bridge, in a four-wheeled coach across the Scottish border, and similar irrelevancies—and decided that 1*d.* would cover them all. At that time the average cost was 8¾*d.*

In 1837 he published his views in a modest little pamphlet entitled *Post Office Reform: Its Importance and Practicability.* It was quickly taken up, and a second edition followed. In this Rowland Hill made a few amendments, one of which improved his original suggestion of prepayment over the counter when the Post Office clerk would mark the letter with a receipt by suggesting that: "Perhaps the difficulty might be obviated by using a bit of paper just large enough to bear the stamp, and covered at the back with a glutinous wash, which the bringer might, by applying a little moisture, attach to the back of the letter...." Thus was the postage stamp invented.

The official reaction to Rowland Hill's idea was epitomised in the statement of the Postmaster-General of the time, the Earl of Lichfield: "Of all the wild, visionary schemes I have ever heard of, it is the most extraordinary."

The Government agreed with this view, and the pamphlet was shelved with other ideas of reformers and cranks. Unfortunately for the country's executive, thousands of people were also reading the pamphlet and getting very different ideas from it. The simple folk of Britain held meetings on village greens and outside factory gates to approve it. Their feeble voices might have gone unheard, but there was a more powerful force coming to their assistance. For once employer and employee were on the same side. Scottish industrialists, labouring with the disadvantage of remoteness and distance from the mercantile centres of London, organised enormous petitions. In London itself the banking house of Baring Brothers was the motive power behind a tremendous propaganda campaign taken up with enthusiasm by merchants and business houses who were sick of the inefficiency and expense of their letter service run, whether they liked it or not, by the Government.

In the two years that followed Rowland Hill's pamphlet the Houses of Parliament were bombarded with petitions and propaganda stunts which jerked the legislators out of their self-satisfaction. In the third year, 1839, not a day passed without another mass of paper bearing thousands of signatures being carried into the Palace of Westminster. There were 2,000 of them in six months, including one from the Lord Mayor and the citizens of London which contained 12,500 signatures collected in twelve hours.

The Government bowed to the inevitable: the Penny Post became law on 17 August 1839, and the system started operation on the following 10 January. The postage stamp, the famous Penny Black, was not ready until 6 May 1840.

Within a month of the start of the Penny Post system, the number of letters nearly doubled. Though this increase was not as great as Rowland Hill had envisaged, the Post Office balance sheet in the first year still showed a profit of half a million pounds. It was a drop of more than a million, which encouraged the Post Office die-hards to repeat their forebodings. But no one else was alarmed. The number of letters was increasing month by month, and even the extra cost of sending mail by the new railways was covered.

Rowland Hill's ten years of work had ended in triumph. The nation was bound more closely together. Literacy became a necessity, and the charge of being " unable to read or write a letter " was a disgrace.

Rowland Hill was virtually ensuring the success of the Penny Post by his sole efforts. The Post Office hierarchy dug in its heels and refused to employ him, and he was compelled to work from the Treasury, where the Post Office Secretary, Colonel Maberley, could still override his decisions. For his work, the Government had offered Hill a niggardly £500 a year and the public violently protested, which resulted in an increase to £1,500. This was still a poor reward compared with the £4,600 income of the Postmaster-General.

Hill's enemies were still out for revenge. After two years, when the scheme was running smoothly, Hill was told that his services were no longer required. Once again the petitions started to arrive at Westminster, and powerful business interests organised a testimonial which totalled £13,000. In 1846, when a Whig Government came to power, Rowland Hill was reinstated, this time in a newly-created post as Secretary to the Postmaster-General. In 1854 his arch enemy, Colonel Maberley, resigned and Hill took real control.

He retired at the age of sixty-nine in 1864, largely through ill-health, but also because of internal clashes with the Postmaster-General. When he had advocated his Penny Post the average British citizen wrote three letters a year. In the year of his retirement 675 million letters a year were pouring into his Post Office letter-boxes.

Belatedly, the Government recognised Hill's services to his country. His salary was made a life pension. A grant of £20,000 was allocated from the Treasury funds. The universities of the world showered honorary degrees on him to add lustre to his knighthood. He lived fifteen years in retirement, dying at Hampstead in 1879. He is buried in Westminster Abbey.

Rowland Hill lived long enough to see his prepaid, flat-rate system copied by the principal countries of the world, and to know that an International Postal Convention had been signed at Berne in 1875, one of the outstanding examples of international co-operation for the mutual benefit of mankind.

Few of the figures whose lives are recorded in this book invented anything so simple as a small piece of paper "covered at the back with a glutinous wash". But with that simple emblem of a brilliant analysis of a transport problem, Sir Rowland Hill joined the ranks of one of this country's and the world's greatest benefactors.

Not the least important result of the arrival of the Penny Post was the state of mind in which rapid and cheap communication for all was regarded as a normal and needful feature of life. The Royal Mail had begun as a personal service for the benefit of the Crown ; it developed into a profitable enterprise, and while it has always retained that feature it also became a public utility service. When, therefore, ideas to speed up communication to a greater degree than that which was feasible with horse or railway reached a practical stage, it was natural that the Government department responsible for the service, the Post Office, should step in. At first, the inevitable caution of the civil servant restrained development of electrical means of communication ; later, to the eternal credit of the Post Office, both in telegraphy and radio, financial and technical help was given with a lavishness and imagination rare in the history of this or any other country's government.

23

GIRDLE ROUND THE EARTH

INVENTION OF THE TELEGRAPH AND TELEPHONE

CREDIT for the first suggestion of an electric telegraph goes to an unknown writer of the eighteenth century. In the *Scots Magazine* of 17 February 1755 appeared an article signed " C. M." which suggested that twenty-six wires should be used to pass a magnetic current to cause a signal at the other end. An impulse on wire labelled A would duly attract a distant magnet, also marked A, and so on through the alphabet. The identity of the writer may have been Charles Morrison, a Scottish surgeon of Edinburgh of the period who was known to be interested in electricity.

The first telegraph apparatus was that of Francis Ronalds, the son of a London tradesman, who was born in 1788. About 1810, at his house in Hammersmith, Ronalds ran nine miles of wire round his garden and sent a current through it which controlled a simple signalling device. An impulse of current generated by friction agitated two pith balls, which moved a dial until the desired letter appeared in a slit. Eventually he got the machine operating with reliability and he offered it to the War Office. Not for the first time or the last, the armchair generals of Whitehall regarded it as a crackpot invention, and stated they were perfectly satisfied with the semaphore stations which were landmarks on every hill between London and the Kent coast at this period of invasion dangers. That the wooden arms were a very slow method of passing messages and were usable only in clear daylight evidently did not worry anybody. Ronalds took the rejection in good part, accepted the experts' opinion as authoritative and gave up his investigations. His system may have been slow and cumbersome by later standards, but it was infinitely faster than any method of communication known at the time.

A more practical approach was that of Edward Davy, who exhibited a needle telegraph in London in 1837. His great contribution was a relay system by which weak currents could be strengthened from batteries placed at intervals. Davy did nothing with his instrument, and shortly afterwards he emigrated to Australia.

In 1837 Charles Wheatstone and Samuel Morse were perfecting their own independent inventions. As a matter of record, Wheatstone made the first working telegraph placed at the service of the public. He was born near Gloucester in 1802, and after a short period at school was apprenticed to his uncle as a musical-instrument maker. The uncle was unimpressed with the youth's capabilities, and the indenture was broken. Wheatstone seemed to have stayed at home reading French poems and plays. This gave him the necessary knowledge to understand a book in French on Volta's experiments with electricity which he found. The work fired his imagination, and at sixteen he was trying out the experiments for himself, making a battery with pennies because he could not obtain copper plates.

Wheatstone was undoubtedly a most intelligent youth, and had a wonderful aptitude for science of the spectacular kind. One trick which brought him a steady income was his magic lyre. The lyre was suspended by a steel rod which went up through the ceiling and into an adjoining room, where a musician playing various solo instruments duly performed. The lyre acted as a sounding-box for the vibrations of the steel rod and, to the audience's mystification, the lyre appeared to render the notes of a violin, piano, trumpet, and drum. Wheatstone so impressed himself with the trick that he proposed laying a steel rod between London and Edinburgh, estimating that sound would travel from one end to the other in three seconds. His name for this device was the telephone. Another invention of his, a sort of deaf-aid, he called a microphone.

At the age of thirty-two he had a great scientific reputation as a professor in experimental physics at King's College, London. While there he measured the speed of electric current, until then regarded as instantaneous.

The wisdom of increasing years taught him how futile was his steel-rod acoustic telephone and he seriously studied electrical methods. In 1837, he went into partnership with a retired Indian Army medical officer, William Cooke, and shortly afterwards a patent on a five-needle telegraph was secured. The needles were located in the looped ends of five wires, so that, with the passing of current to deflect any one of them, a wide variety of signals could be made. This device was erected and in use in 1837, and Wheatstone and Cooke were regularly conversing by means of it.

The first big installation was along the London–Blackwall Railway in 1838, and later on the Great Western for a distance of thirteen miles down the line. These installations were used for railway business and were available to the public. The latter refused to take the telegraph seriously until it was responsible for the arrest of a murderer. A woman was found dead one morning after a man had been seen leaving the house hurriedly. It was discovered that he had taken a slow train to London. Over the telegraph went his description, ending with the sentence : " He is dressed as a Kwaker " (the five-needle code had no Q). At Paddington a man in the distinctive Quaker costume of the time was arrested and, in surprise and consternation, promptly confessed.

This thwarting of a criminal's flight proved to the public the value of the telegraph, just as the somewhat similar instance in the Crippen murder case did for transatlantic wireless telegraphy in July 1910. Wheatstone's system, in a simplified twin-wire form, became widespread.

An electric clock in 1840, a teleprinter in 1841, and an automatic transmitter capable of passing 100 words a minute some twenty years later were other Wheatstone inventions. He was knighted in 1868, seven years before his death.

The point of historical interest is that the Wheatstone telegraph was perfected a little time before Samuel Morse's instrument proved its worth in America. The result was that

Morse was refused a patent in Britain, though his device was more efficient. Morse's great triumph was, of course, his telegraph code—a simplification which brooked no imitators.

Very soon the possibility of international communication fired the imagination of both inventors and the public. Indeed, a few experiments had been made as soon as Wheatstone's device was invented. Sir William O'Shaughnessy Brooke sent an impulse through an insulated wire lying on the bed of a river in India in 1838. A year after Morse successfully laid a cable in New York Harbour, Charles West, an impecunious but ambitious Englishman, attempted a one-man enterprise of laying a cable between England and France. For some reason, he chose Portsmouth as the starting place and he showed that water had no effect on the wires by sending a message from the boat in the harbour to the shore. He got no further than this. This sort of individual effort, because of the unbelievably unco-operative attitude of both investors and Government departments, was the rule.

Two brothers named John and Jacob Watkins Brett pestered Parliament for permission to lay a cable between England and France, and in 1850 laid one from Dover to Calais at their own expense. The opening ceremony was duly arranged with notabilities on each side preparing to send messages of greetings. After a few faint signals there was an abrupt silence, and the line was proved to be broken. The official wiseacres voiced the opinion that this debacle confirmed their own views about undersea telegraphs. What had happened was that a French fisherman out in the Channel had hauled the cable up with his trawl and, thinking that he had found a new kind of submarine ore, hacked out a piece of the cable to prove to his friends that his story was true. The news of this accident reversed opinion about the possibility of a Franco-British telegraph system, and the damaged cable was quickly replaced.

When the task of laying a cable between England and America was proposed, it was Professor William Thomson who gave the cable-makers scientific data based on a theory which proved exact in practice. This early work of Thomson foreshadowed the contributions that were to come from the most

102 The *Great Eastern*, used to carry 4,000 tons of cable to link the Old World and the New by telegraph in 1865–6.

able scientist of his generation, better known as Lord Kelvin.

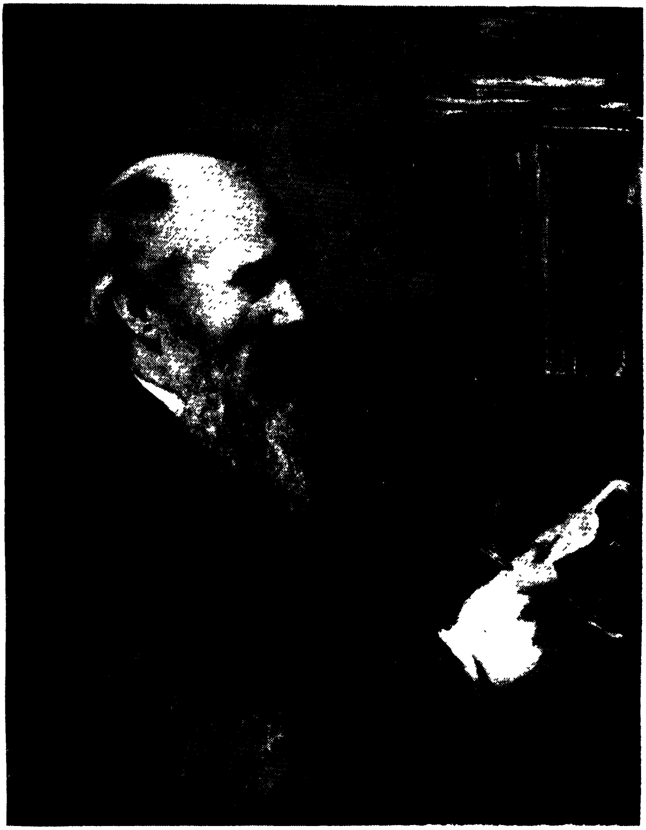
William Thomson was the son of a Belfast schoolteacher, a widower with a passion for mathematics. In 1832, when young William was eight, his father secured the chair of mathematics at Glasgow University. William used to attend his classes as a visitor, sometimes answering problems which defeated the students. At ten he entered the University, and seven years later went to Cambridge.

With Thomson's calculations completed, the work of laying the cable could be planned. Most of the enthusiasm for a transatlantic cable arose in the United States. Cyrus Field, an American industrialist, was the dynamic personality behind the scheme, and he gave a twenty-six-year-old British telegraph engineer named Charles Tilston Bright the job of laying the cable. In co-operation with the Brett brothers, Bright started what was to be nine years of heartbreaking and dangerous toil before success was achieved.

By August 1857 the first section was laid as far as Valencia, Ireland. The American and British Governments supplied two warships to lay the Atlantic section. H.M.S. *Agamemnon* was to lay the first 1,000 miles and the U.S.S. *Niagara* the second. After 380 miles, the cable snapped and was lost. Both ships returned to England, and nine months passed before sufficient money was raised to buy new cable. Once again each ship set out with 900 miles of cable on board—and encountered phenomenal storms for the time of the year (it was June 1858) which lasted a week. Many members of the crews were injured and the *Agamemnon* nearly foundered before she limped back to port. For the third time finance had to be found. This time the project was crowned with success, and the plan of an American, turned into reality by British engineers, linked the Old World and the New between Valencia and White Strand Bay, Newfoundland. For just two months the cable functioned. Then, somewhere on its 2,000 miles of undulating length spanning gorges and mountains of the submarine world, there came a break.

The *Great Eastern*, mightiest ship of her time, was used for the next attempt. The engineering work was in the charge of Samuel Canning, with Bright as adviser. Much stouter cable was used—4,000 tons of it—but once more there was trouble, and the cable broke. Still another was sent out, and permanent success was achieved when the first message flashed across on 27 July 1866.

It is difficult for the modern person, accustomed to news from every corner of the earth to be on his radio news bulletin or in his newspapers within a matter of an hour of its occurrence, to realise that less than a century ago even two great nations like the United States and Great Britain were not only separated by thousands of miles in space, but many days by time. It was a triumph of British technical skill coupled with the optimistic persistence of American business enterprise which first annihilated time, and as a result Sir Charles Bright, before his death in 1888, saw a world where every ocean hid a telegraph cable and the principal nations of the world were able to communicate with greater speed than had a couple of adjacent villages when he had been a boy. Important as the invention of the telephone was, it did not have the dramatic impact of the telegraph on modern civilisation; even Marconi's



103 William Thomson (later Lord Kelvin) introduced the telephone to Britain in 1876.

miracle of communication without wires, indisputably a far greater technical miracle, did not cause such a revolution in the world economy.

The telephone is, of course, primarily an American development, though Britain may be proud that Edinburgh, that town which has mothered so many men of science and learning, nourished Alexander Graham Bell, its inventor. Born in 1847 to a family which for generations had devoted itself to the arts of speech (his father wrote a book called *Visible Speech* which is a classic on the subject of lip-reading for the deaf and dumb), Graham Bell and his brother made a talking machine which could imitate the word " mamma " while both were still in their 'teens. After graduation, Bell went to London and earned his living as a teacher of elocution, and there became interested in experiments of German physicists with tuning-forks actuated by electrical currents. This study brought him into contact with Wheatstone, who told him of the " enchanted lyre " trick of his early days. When Bell emigrated to Canada, and later obtained a professorship in Boston, U.S.A., this country lost a great nineteenth-century figure. With reason, the patent on his invention which was granted to him on 14 February 1876 has been called " the most valuable single patent ever issued ".

The refinement which improved Bell's instrument and gave the world the telephone as it is known to-day was the work of David Edward Hughes, born in London in 1831. His family took him to Virginia in 1838, where he eventually became a music-teacher. He was fascinated by the transmission of signals, and at the age of twenty-two devoted himself entirely to research. Very quickly he perfected the teleprinter, which was patented in 1855. Some twenty years later he returned to England and in 1878 patented his carbon microphone. This was a far more sensitive microphone than Bell's. The first one which Hughes produced astounded engineers by reproducing the sound of the footsteps of a fly crawling across the mouthpiece.

The telephone was first introduced to Britain in September 1876, when Kelvin (then Sir William Thomson) demonstrated Bell's device to members of the British Association meeting in Glasgow. A particularly lively official, William Preece, the Post Office chief electrician, advised the Government to provide a telephone service for the public. The Treasury pondered on the point, and eventually, in August 1878, agreed that instruments should be hired from the inventor and then rented at a profit. Whitehall had been too slow. A private company had already been registered to perform this remunerative service, and soon there were several more firms in the field. Competition was hectic, and rival companies were preparing to open exchanges in London to serve identical areas. With this sort of commercial competition, the civil service was an " also ran ". Most alarming to the Exchequer, the telegraph monopoly was being assailed, and so the Government's legal advisers were invited to say that in their opinion a telephone was a telegraph and a telephone conversation a telegram. They obligingly confirmed this, and the Courts upheld their opinion in a subsequent action in December 1880. The Post Office then became the sole telephone operator, though continuing to allow the companies to function under licence. The final take-over was in 1911.

Long before then the telephone had revolutionised social and business life in Britain. It helped to abolish the messenger boy and that pathetic, underpaid cypher of the Victorian office, the correspondent, who spent his life writing brief messages and telegrams, which were now largely dealt with by vocal means.

The telephone, and its younger, labour-saving device, the typewriter, brought an innovation to the commercial scene of the early twentieth century which was revolutionary : the girl clerk.

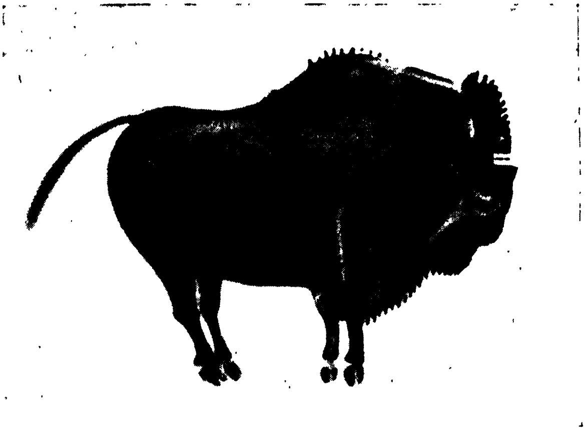
24

LIGHT AND SHADOW

PIONEERS IN PHOTOGRAPHY

THE desire to register the fleeting scene passing before the human eye is as old as humanity. From the cave drawing to the modernistic painting, man has been compelled to set down the picture as he sees it. As natural as his desire to capture mood and colour as well as physical appearance was the ambition to make an absolutely accurate reproduction, with detail exceeding that which the human eye could instantly register or the human brain retain. To-day this cold, scientific portrayal in the photograph is an intrinsic part of our lives. We expect a close-up of the mountains of the moon just as we demand a stratosphere view of the curving earth. The photograph records events big and little—the birth of a prince and the holiday scene for the family album. Its eye probes into an ingot of steel or the cell of a virus. The photograph, whatever the cynics may suggest, is the portrayal of truth.

It is difficult to believe that only a little more than a century ago no perfectly accurate record was possible. Generation after generation of enquiring scientists had probed into the possibility, without result. One of the first of these explorers into the realms of photography was Roger Bacon, whose name pops up with regularity in the preliminaries of most of our modern inventions. Sometimes his ideas were the children of a busy imagination, and the prophecy was not fortified with any theory of method. But his thoughts about cameras and lenses were more practical. It was about 1267 that he noted a shaft of sunlight streaming through a hole in the wall of his workroom. The beam expanded and on the opposing wall it produced a vague, shadowy picture of the leaves on the tree through which it passed before entering the twilight of the room. Bacon was, in fact, sitting inside a crude camera.



104 Graphic art is as old as intelligent man: a cave drawing of 30,000 years ago.

This phenomenon was also known to Leonardo da Vinci, and a little later a compatriot of his, Girolamo Cardan, made experiments with mirrors and curved glass in order to control beams of light. In seventeenth-century England Robert Boyle made a portable camera obscura which would reproduce a miniature of a scene on a piece of plate glass behind the lens. Artists who lacked the quality of talent but could own to resources of ingenuity used to copy this ready-made picture in order to save work.

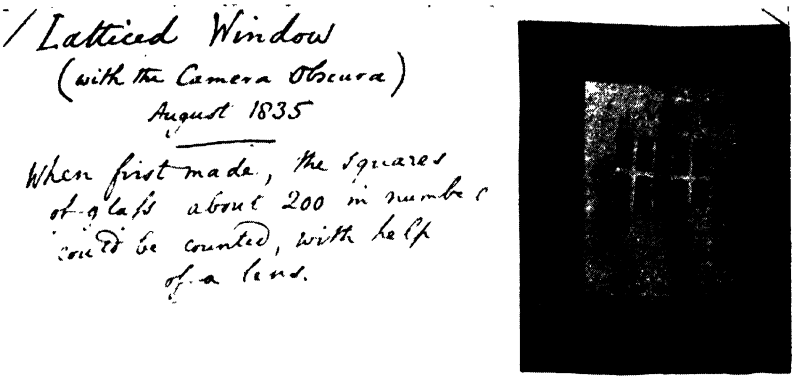
They must have wished that there was some magic method of having the picture transferred instantaneously to the paper. A natural substance did, as a matter of fact, exist for treating that paper, and its peculiar behaviour in light was known. At the Freiberg silver mines in Germany a sixteenth-century astronomer had duly noted that some of the ore, vitreous and dull when it was first exposed by the pick, quickly assumed a violet-black hue when exposed to sunlight. The miners called it "horn silver" and they always took care to keep it in the dark so as not to spoil its market value.

These little items of knowledge needed welding together, and the opportunity to do so came in the meetings of the Lunar Society, so called because the meetings (usually held at the home of Josiah Wedgwood, the potter) took place on the night of the full moon for the convenience of the members leaving for home around midnight. This Society was a remarkable body, comprising some of the most cultured and scientific men of the day. Among the members were Josiah Wedgwood, Sir William Herschel (the astronomer), James Watt, and Dr. Joseph Priestley (the chemist).

Josiah was a wealthy man. He advertised for a tutor for his son. The man who obtained the post was Alexander Chisholm, who had previously worked with a chemist named William Lewis at Kingston-on-Thames. Lewis knew all about the properties of horn silver and had attempted to make silhouettes with it. Chisholm told his pupil, Tom Wedgwood, about these experiments and immediately aroused the latter's interest. Wedgwood, a young man of twenty-two, was helped in his work by Humphry Davy, a lad still in his 'teens. Exactly what these two did, and when, is not known. But James Watt undoubtedly helped them. It is believed that the objects photographed were leaves and the reproduction was made on leather previously treated with horn silver. There is, however, little doubt that these light-and-shadow pictures were being made between 1794 and 1796, giving the young men a glimpse of a new art and industry before the entire picture blackened before their eyes.

They also tried reproducing the picture given in a camera obscura. In this they were unsuccessful. Lack of light and poor definition made any recognisable shading impossible. Nevertheless, before Wedgwood died at the early age of thirty-four in 1805 he was able to put on record the details of these early experiments. His memoir was published in 1802 entitled *An Account of a Method of Copying Paintings upon Glass, and of Making Profiles by the Agency of Light upon Nitrate of Silver. Invented by T. Wedgwood, Esq., with observations by H. Davy.*

Whether Wedgwood did anything further with his invention is not recorded, though there was a remarkable clue to his activities which came to light many years afterwards when the house of Matthew Boulton (James Watt's partner) was being cleared of lumber. A silvered copper plate was found bearing a picture of the famous Soho works of the partners.



Latticed Window
(with the Camera Obscura)
August 1835

When first made, the squares
of glass about 200 in number
could be counted, with help
of a lens.

105 The first dated photograph : "A Window in Lacock Abbey" taken by Fox Talbot on a paper negative in 1835.

A story was also told that Watt and his friends used to take portraits of people, but an artist acquaintance begged the Lunar Society to abandon the experiments, " as were the process to succeed it would ruin portrait painting ".

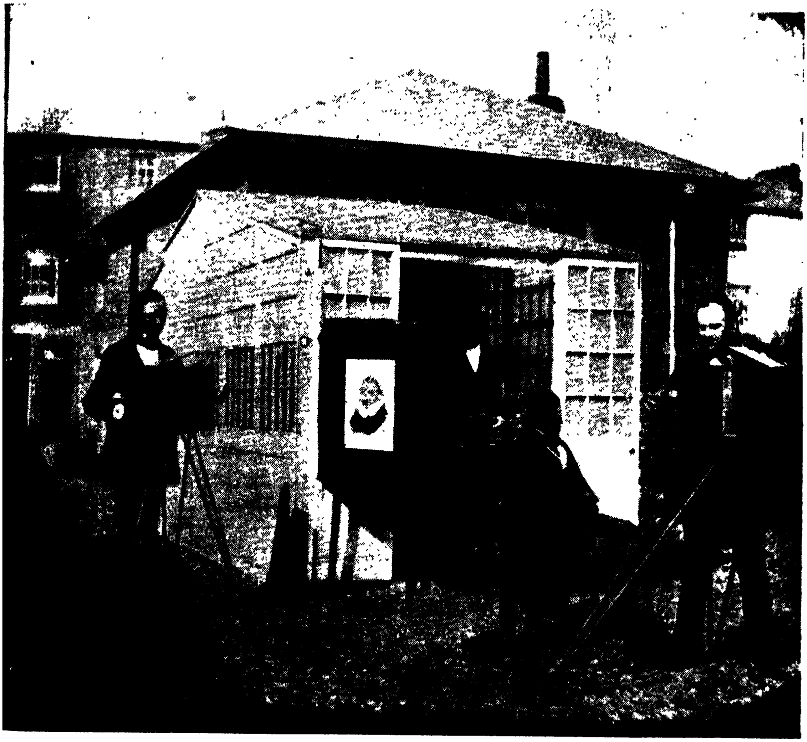
It is almost certain that the Soho photograph must have been taken after Wedgwood's death if the image on it had been fixed, because the best way of doing this, with hyposulphate, was not discovered until 1812 by John Herschel (son of the astronomer), who pointed out that the chemical would dissolve silver chloride.

Meantime, other inventors were busy, notably in France, where Isidor Niepce worked for years before his death in 1835 on the very brink of success. He had earlier been joined by Louis Daguerre, who was making detailed pictures between 1835 and 1837. These were the first real photographs shown to the public, though some rather vague pictures called " heliographs " had been shown to his friends by Niepce as far back as 1826. The method of making daguerreotypes, as they were called, was demonstrated by their inventor before an audience of scientists in Paris on 19 August 1839, and an enlightened Government, realising the importance of the invention, proclaimed the new pictures as a gift to the world, so that no patent was allowed, Daguerre being given an annuity of 6,000 francs. Rather astutely, however, the Frenchman had taken the precaution of patenting his process in England a month earlier and he gained a very large income from royalties from its use in this country for many years.

The contention that Daguerre is the true inventor of the first practical system of photography has aroused disputes ever since. The arguments are not really of very great importance. Daguerre was a pioneer, and through the help of his Government he gained a commercial lead. But he was only one of many doing research and nearing success at the time.

His rival for the honour of the invention of photography is William Fox Talbot. It is sometimes said that Daguerre hurried his announcement when he heard of Talbot's progress, and often claimed that Niepce's and Daguerre's preliminary developments set Talbot on the road to success. Actually the processes were very different. The daguerreotype was made on a silver plate or silvered copper plate. First it was rubbed smooth and then polished with rouge and cotton wool. When thus prepared, it was placed in contact with a thin layer of iodine, which changed the plate's colour to a bluish-violet. After exposure for anything up to twenty minutes, the plate was put in a box with warmed mercury, the vapour developing the picture. Fixing was achieved by hypo-sulphite of soda. The only important change in the method in later years was the use of bromine instead of iodine.

Fox Talbot reached success along a very different but almost as lengthy a road. He was born at Lacock Abbey, Wiltshire, in 1800. A member of a well-to-do family, he was educated at Harrow and Cambridge, gaining distinction in mathematics. His interest in botany and anthropology occupied his early years after coming down from Cambridge, and an indication that he was no haphazard amateur is shown by the fact that he was a leading authority on the translation of Assyrian cuneiform characters. At the age of thirty-three he was in Italy. Touring around Lake Como, near the Swiss border, he tried to make painted pictures of the scenery with a device known as a camera lucida. The accurate detail of the picture thrown on a glass screen by this device started him on investigation into photography. A negative made in 1835 (the first dated one on record), showing a view of a window at



106 An early Fox Talbot calotype showing the inventor's studio at Reading.

Lacock Abbey, indicates that within two years he was getting good results. But he was cautious in making any wild claims until he was satisfied with his work, and it was not until 25 January 1839 that he allowed some of his photographs to be shown to the Royal Society, and on 31 January he read a paper to the members entitled "Photogenic Drawing". The Fox Talbot patent was registered on 8 February 1841.

The tremendous advantage of the Fox Talbot method was that copies could be made: his original was a negative. In his early experiments he followed the custom of making silhouette prints by placing objects direct on the paper. This material was prepared by plunging a sheet of paper into a solution of common salt, and then in a silver solution. The image was fixed by washing in a hot solution of salt, which removed a greater part of the silver. Then he greatly improved on this paper for use in a camera. Either iodide of silver or nitrate of silver was first soaked into the paper, then iodine or potassium, and finally gallate of silver. It was much faster than the Daguerreotype method, making a clear picture in a minute or so under good conditions. After fixing, the paper was rendered translucent with wax and positive copies made. There was a tendency for extraneous detail to get in through the roughness of the paper and specks of dirt which it was almost impossible to eradicate until glass was adopted for the negative.

The calotype, as the Fox Talbot photograph was named, gave very beautiful results within a few years. The inventor's *Pencil of Nature*, published in 1844, is the earliest literary work illustrated with photographs, and this was followed in 1845 by *Sun Pictures in Scotland*, in which the Scottish artist, David Octavius Hill, co-operated. Some of the photographs in this book show artistic qualities which have hardly been excelled since.

During his long life—he died in 1877—Fox Talbot continued to improve his invention. He achieved the engraving of a photograph on a steel plate in 1852, and in 1854 used albumen to give the well-known gloss of the modern photograph. He was also the first to suggest experiment with methods of breaking up the picture into dots for half-tone reproduction by printing, using silk gauze, muslin, and lines ruled on glass for the purpose.

The contentious subject of the pioneer of photography is further aggravated by the claims of Joseph Reade, a chemist and microscopist of Leeds. He seems to have a fair claim to have been the first to produce a paper negative with gallic acid and silver nitrate and to fix a photograph with hypo, both ideas being tried by him in 1837. He also was the first to use tannin as an " accelerator ". Reade did not, however, publish details of his work at that time, so that his record, like that of so many secretive inventors, is merely a matter of historical interest.

Another British name deserves to be mentioned—that of Frederic Scott Archer, born at Bishop's Stortford in 1813. He invented the wet collodion process in 1848 and published details of this method of preparing the photographic plate in

March 1851. Very quickly it virtually replaced both the daguerreotype and calotype, remaining in popularity until the eighteen-eighties. It gave a very clear, fine grain, clear whites, and was easy to fix. The comparative ease with which the plates could be prepared brought photography within the reach of amateur enthusiasts, and the enormous market thus opened created a prosperous industry. Yet Archer lived and died a poor man. On his death in 1857 a public subscription was opened for his widow and children. In an article addressed to the " sons of the Sun ", *Punch* appealed for help with the words : " The inventor of collodion has died, leaving his invention unpatented to enrich thousands." Yet the donations totalled only £747. Soon afterwards the widow died and the children were left entirely dependent on the remainder of the subscription. Belatedly but meanly, the Government voted them a pension of £50 a year. If their father's idea had been patented, it would have brought the Archer children as much money every week.

The collodion process gradually gave way to dry plates in which gelatine was used in conjunction with bromide of silver. The idea was proposed in 1871 by Dr. R. L. Maddox, but the plates were slow in their reaction to light and results were uncertain. Joseph Swan, the inventor of the electric lamp, and at that time working in a chemist's at Newcastle, discovered that the difference in the behaviour of the plates was due to differences in the temperature at which the emulsion was prepared and the length of time it was kept hot. Swan did not patent or publish his discovery, but used it for the manufacture of dry plates which rapidly gained his firm an unrivalled reputation. Two years later, in 1879, Swan invented the bromide printing paper which is in universal use to-day, and made it possible to print photographs very rapidly by artificial light. These two advances, with the American Eastman's improvements of the film base, brought photography within sight of its present perfection. They also made possible the invention of photography's younger branch—the cinematograph film.

25

PICTURES THAT MOVE

THE BIRTH OF CINEMATOGRAPHY

THE story of the invention of the cinematograph is a most appropriate one, with all the ingredients of flamboyant plot, fortunes lost and made, and romance in a melodrama which even a script-writer would hardly dare to mix for the entertainment of cinema patrons and suggest were true. The drama has an international cast, but it is now established beyond all doubt that the leading player was British.

The early gropings by mankind to reproduce movement visually go back to the birth of civilisation. There is undoubtedly a religious significance about it, with the desire either to suggest immortality or to gain ascendency over animals or enemies by being in a position to control their actions at second hand. Most cave drawings fall into the latter category ; a few of them are actually shadow pictures, the outline filled in with colouring from the image thrown on the wall by the animal-fat lamp. In later times the magician-priests of the Middle-East civilisations studied the science of optics and the phenomena of light in order to provide religious mysteries enacted on special days in their temples. Such shadow dramas were general throughout the history of ancient Egypt. In the present era experiments were continued : by the Arab astronomer Al Hazen in the twelfth century, by our own Roger Bacon in the thirteenth century, and later by Leonardo da Vinci. These objective studies degenerated into trickery for charlatans dabbling in black magic, and the revelations in the evidence at sorcery trials in the seventeenth and eighteenth centuries of the conjuring up of devils, skeletons, and the like were undoubtedly accounts of early cinema tricks. It is interesting to note that the first optical toys of the early

Victorian era showed similar black-magic symbolism: the devil waving a pronged stick, a dancing skeleton and so on.

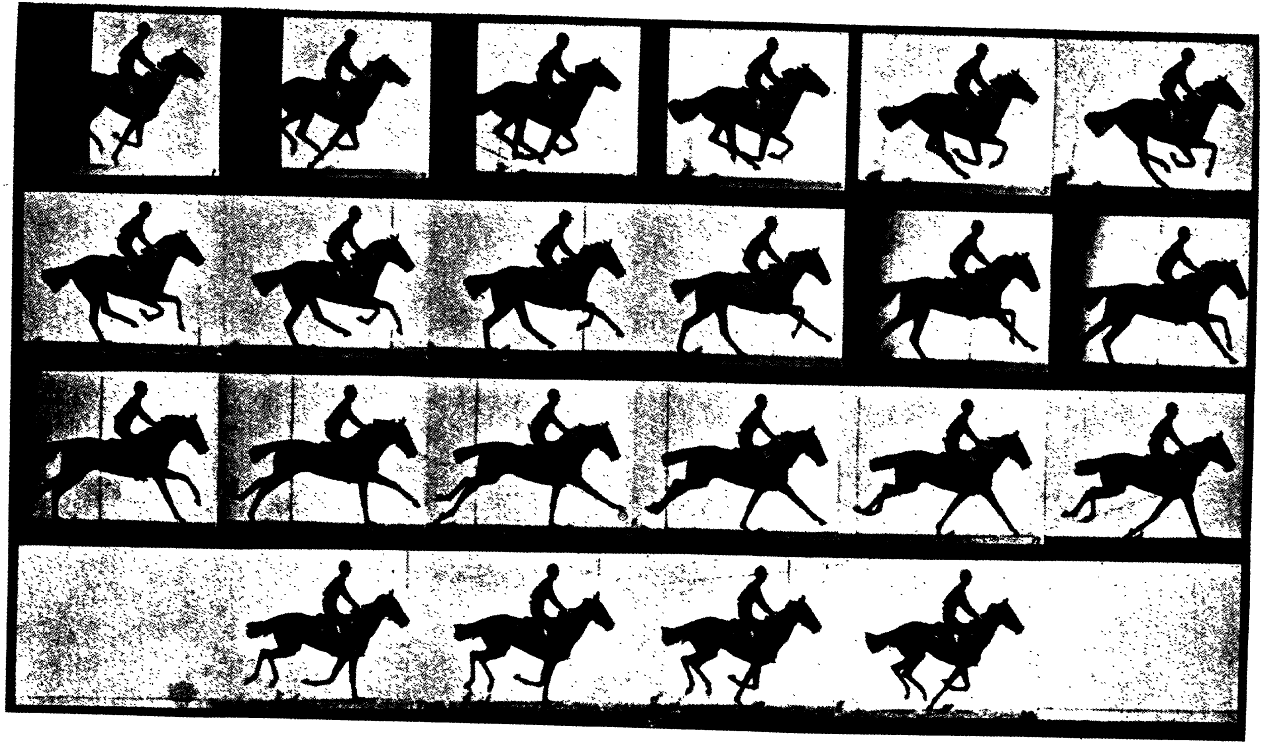
The culmination of these simple devices for projecting a picture or giving the illusion of movement (only a few of them achieved both at the same time) culminated in the magic lantern which was so popular in the late nineteenth century and has had a second lease of life in the film-strip projector of to-day. Such reproduction of motionless pictures has little to do with cinematography, which is based on the persistence of vision of the human eye—or, more simply put, the inability of the human nervous system to transmit pictures to the brain if they are changing faster than twelve times a second.

The simplest evidence of this " optical stammer " is supplied by watching a spinning coin, when a blurred image of both heads and tails will be seen simultaneously—a fact noted by Sir John Herschel in 1826, who seems to have been the first to call attention to it. Friends of Sir John commercialised the idea in a variety of toys, some of which had slots through which different forms of a basically similar drawing gave the appearance of movement. In every well-to-do nursery of early Victorian days these wheels were as normal a piece of furniture as musical boxes. The best were made by William Horner. Very soon after this, photographs were available and the most important experiments in using them were conducted in other countries, notably by Dr. Sellers of Philadelphia.

The possibility of taking a continuous stream of pictures with a camera had to await the invention of a flexible medium to take the place of glass. This came in the 'sixties with the invention of a form of celluloid called " parkesine " by a Birmingham chemist named Alexander Parkes, who was attempting to produce substitutes for ivory and tortoiseshell. Even without this seemingly essential ingredient of filming, an Englishman made a bizarre experiment which has become an historic event in the progress of the industry. His name was Dr. Edward James Muybridge, a native of Kingston-on-Thames. His life reads like a magazine adventure story. While working in America, he fell on his head and this undoubtedly affected his brain slightly with eccentric effect, though he was certainly not unbalanced by any medical standard. He also killed a man who was attempting an affaire with his wife, being acquitted on the traditional but unwritten law which applies to such crimes of passion. This was in California, where he was at the time engaged in taking photographs of a horse in order to settle a wager between the Governor of the State and a couple of business-men.

The argument was on the subject of a horse's feet in a gallop: did all four leave the ground simultaneously? With 25,000 dollars at stake, the Governor, Leland Stanford, was ready to pay Muybridge all the expenses he needed to prove his case. The scheme was to set up a couple of dozen cameras in a row, with threads to be broken by the horse as it galloped by, thus actuating the shutters in turn. There was too much slack in the threads for this method to work, but with a simple electrical device the twenty-four shutters were successfully operated, the pictures came out, and the Governor won his bet. Afterwards Muybridge was employed to photograph the movements of all sorts of living things in the same manner at the Philadelphia Zoo, and the pictures were eagerly bought by artists, sculptors, naturalists, and the merely curious. Always something of an exhibitionist, Muybridge loved the artistic and learned circles in which he now moved, and on his return to England his flowing locks, unkempt beard, and long cloak were a familiar sight in the West End of London and his native Kingston-on-Thames until his death in 1904.

Muybridge's pictures, even when projected, were not really a moving portrait of the actual thing, because each one was photographed from a slightly different position. A man who got nearer to the goal was a Frenchman, Louis Le Prince, who came to England and married the daughter of John Whitley, owner of a famous firm of brass-founders in Leeds. Le Prince ran an art school in Leeds, and in conditions of great secrecy he had a projector and camera built to his own specifications. The films he used were of oiled paper and in 1880 he made a moving-picture record of the people on Leeds bridge. No actual report of the screening exists, because of the mania for secrecy which Le Prince had, but it seems



107 These photographs of a galloping horse were part of a series taken by Dr. Muybridge demonstrating the movements of horses and other animals.

certain that the first real moving film picture was shown either in 1888 or 1889 in a small whitewashed room set aside for his experiments at a deaf-and-dumb school where his wife taught. A year later Le Prince left to visit relations in Dijon, France, taking all his equipment with him. His brother learned of his work and suggested that America would offer better chances of commercial success. The unwieldy apparatus was packed up, the ticket for Paris bought, and the brother bade him farewell on the *Rapide* for Paris. That was the last ever heard of him. Despite a search which was continued from that September of 1890 until very recent years, no trace of Louis Le Prince or his apparatus has ever been discovered.

Before this mysterious tragedy the real stars of this strange historical drama had come on the scene. Their names are John Roebuck Rudge and William Friese Greene. The former was an inventor by profession who had interested himself in motion pictures as early as 1862, but lack of funds prevented his completing his experiments until William Friese Green offered to co-operate. A native of Bristol who set up as a portrait photographer in The Corridor, Bath, Friese Greene saw the necessity of using flexible film base, and his first material was made in the kitchen of his house in Gay Street, Bath, where rows of kettles spouted steam on the sheets of parkesine until they were soft, when they were quickly rolled thin between the rollers of a laundry mangle. After being sliced into strips and coated with emulsion, the film was ready for loading into the camera which Rudge and Friese Greene had perfected between them.

Despite the experimental work he was doing, Friese Greene did not neglect his business interests. He had a chain of portrait studios, including some in London, and while visiting one of these he made his first film: the traffic at Hyde Park Corner. This was in January 1889, and he took the exposed film to a small laboratory he had at Brooke Street, Holborn. Late that night development was completed and the film fed into a projector. On the opposite wall the life of Hyde Park Corner hours before was re-created in jerky, rather blurred, but authentic moving pictures. Rushing out into the wintry

108 Friese Greene shows the first moving pictures to a passing policeman (from the commemorative film *The Magic Box*).

streets, Friese Greene grabbed the only person he could see —a policeman on his nocturnal patrol. The man stumbled away from that dingy little building a few minutes later muttering with the simplicity of great truth, " I've seen a miracle."

But miracles have a habit of causing a sensation while failing to teach a lesson. Neither the photographic trade nor the public regarded the Friese Greene pictures as anything more than a novel trick. Even the great Edison, with whom Friese Greene corresponded, preferred to concentrate on the peepshow idea for his moving pictures, which would need no projector and would entertain one person at a time in an amusement arcade. Friese Greene poured his considerable wealth into improving his invention, spending all his time on it and neglecting his business until it declined for want of attention, so that two years after that epoch-making event on a winter's night in Holborn he was in prison for debt. Everything he owned, including apparatus which would to-day have an honoured place in any museum, was sold off as scrap or valuable only for breaking up to get the lenses and mechanism. On his release from prison, he began work on a new camera and he became identified with the group of professional photographers living in the Brighton area, which by 1896 was the chief centre of production of films in Britain. Although the French Lumière Brothers organised the first cinema exhibition for the public in Britain (20 February 1896), thus inaugurating the commercial cinema show, dozens of British photographers were soon busily making films. A one-time partner of Friese Greene, Esme Collings, who was a fashionable Brighton portrait photographer, produced thirty films in 1896, one of which is believed to be the first ever made in which a known actor appeared. This was an excerpt from *The Broken Melody* with a well-known stage figure of the time, Van Biene, playing the principal part.

More important was the work of R. W. Paul, a scientific-instrument maker of Hatton Garden, who gave the first performance in this country of British motion pictures projected on to a screen at which an admission fee was charged. He was also the first to sell projectors and films, and at the studio he built in Sydney Road, New Southgate, some fifty films a year were made.

Mr. Paul died as recently as 1943 at the age of seventy-four, and shortly before his death he showed the writer a paragraph from his catalogue of 1902 which described the studios of those days:

> The large studio, adjoining my new Southgate works, is at the disposal of customers requiring the production of special advertising or other scenes, and is provided with paint rooms for full-size scenery, under the supervision of a competent artist, and a stock of about fifty backgrounds ready for use. The stage-traps, bridges and wings enable any stage performance to be animatographed, as will be seen by the description of many of my new subjects below, all of which were produced here. This building,

erected to my own designs, which is the only one of the kind in this country, enables the photographic effects to be perfectly controlled.

Films were booming. Every travelling fair, every music-hall, almost every assembly hall in town and village was advertising " animated pictures ". Each item lasted only a minute or two, but thousands of such films were made in the last three years of the nineteenth century. And William Friese Greene was almost forgotten. This country was the great film-producing centre of the world until the outbreak of the First World War, when America took the lead. During the war the man who had invented one of the major industries of the modern world was in almost desperate straits, and a few friends circularised the leading members of the cinema industry for donations. It was a time when wartime wages were bringing enormous profits to cinema-owners, but the call met with little response—a total of less than £150 being collected. As a body, the cinema industry is a generous giver to good causes. The poor response was not meanness, but ignorance. Friese Greene was an unknown name.

The time came when the fortunes of the many hundreds of people showing and making films also took a downward curve. The slump after the war and the virtual monopoly which America was creating through the work of a number of brilliant producers and the evolution of the star system brought a serious crisis. An attempt was made in May 1921 to find a way out. Producers came to London to attend what was to all intents and purposes the requiem of a once-flourishing entity. One man, a shabby, gaunt figure, refused to take a defeatist attitude. Only a handful of his audience recognised him as the man who had made motion pictures possible : Friese Greene. The fervour of this unknown enthusiast of sixty-five won the meeting over. His appeal to carry on brought murmurs of approval, and when he finished speaking petty jealousies had been swept away and there was a determination to try co-operative effort to offset American competition. But the man who had spoken so fervently was sitting very still—alarmingly still. He was dead, and at the mortuary the only assets he had were all found in his pocket, a few coins amounting to 1*s.* 10*d.*

To-day in Highgate Cemetery may be seen his gravestone which bears the words:

> WILLIAM FRIESE GREENE
> The Inventor of Cinematography
> His genius bestowed upon humanity the
> boon of commercial cinematography, of
> which he was the first inventor
> and patentee

Thirty years were to elapse before the great industry he founded was to honour him, as was his due, in the Festival film of 1951, in which artistes and technicians, writers, and producers combined to put on celluloid the story of his life as a record for the tens of millions of people who visit the cinema every week in the motion-picture theatres of the world.

26

ANNIHILATION OF SPACE

EARLY DAYS OF RADIO

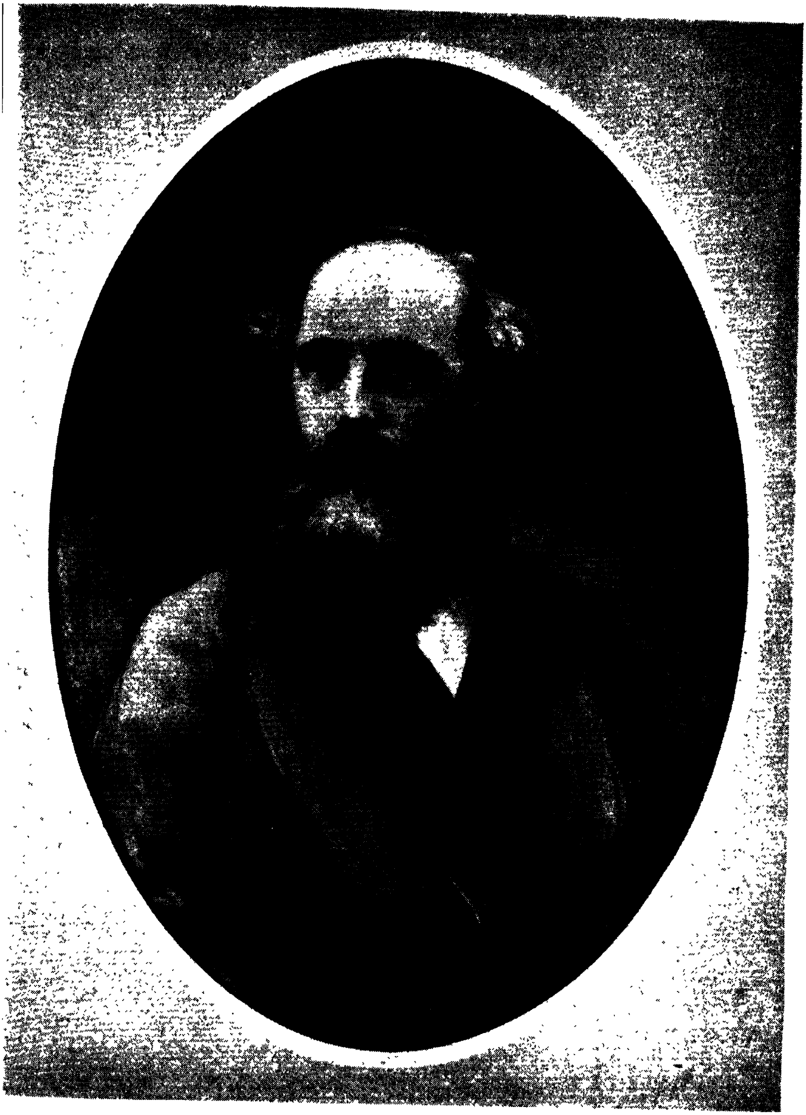
FEW mathematicians have propounded a theory which has caused a social revolution and directly created a great industry. Their painstaking work more usually adds to knowledge and has, from a practical viewpoint, no immediate commercial use. To most people, for example, Newton's theory on the laws of gravity is associated with the rather childish story of an apple falling on his head, and few could say what difference his work made to their lives.

But James Clerk Maxwell, one of the great explorers in the realm of matter, was a mathematician whose paper work paved the way to the invention of radio and thence to the huge electronics industry, broadcasting, and the commercial communications services of to-day. The date of this epoch-making occasion was 1865. Maxwell was born in Edinburgh in 1831. He was fortunate in his upbringing, and from an early age his widowed father encouraged him in his bent for learning, so that when he went to Cambridge he was endowed with knowledge unequalled by any other undergraduate or, indeed, many of his tutors. Maxwell's father had crammed the boy's brain with all the knowledge that science so lavishly provided in the nineteenth-century Scottish capital, but it was disjointed and undisciplined, a defect which his tutors at Cambridge soon changed, though not without cost, for Maxwell was overworked and suffered a serious breakdown in health. But he went on to gain a fellowship, and was thus enabled to devote his life to science and mathematics. He met Faraday and became fascinated with the subject of electricity. Unlike most of the workers on the science of his day, Maxwell made only the simplest experiments, preferring to delve into theory by mathematical calculation to produce results.

His work brought triumphsant reward, for he was able to prove, twenty years before the first radio signal was detected, that radio waves must exist, and that their speed was that of light, 186,000 miles per second. In the state of knowledge about electricity at the time, his discovery was so revolutionary that many scientists objected to it. The idea that any alternating current not only could but must produce radio waves could not at that time be shown in a laboratory experiment because the waves from a piece of wire carrying a current were so long that they could never be recognised as such. Maxwell, in showing by mathematical equations that they existed, was a true prophet of radio science, but not the inventor.

Even if there were objections to his theories, Maxwell's personality did much to see that others worked on proving by practical methods that he was right. He was an unusual man. No dry-as-dust thinker, he loved meeting and talking with people, and his pawky Scottish humour disarmed those who came to refute his ideas as those of an unpractical crank. In the world of science his personality was probably best loved as one of the leading lights of the Red Lions, an official dining club of the British Association. This group of men, who took their name from the Red Lion Inn at Birmingham, had a tremendous influence on scientific thought in the middle of the nineteenth century. It is appropriate that Maxwell became the first professor of the Cavendish Laboratory at Cambridge.

So far as definite development goes, Maxwell died, at the age of forty-eight, four years before the German Heinrich Hertz demonstrated the truth of his theories by transmitting and detecting radio waves across a room in the laboratory. Yet there is irrefutable evidence that this had been secretly achieved in London about the time of Maxwell's death. The little-honoured man was David Edward Hughes, born in London in 1831 of Welsh parents. A few details of his work were given by Sir William Crookes in 1892, but Hughes himself did little to see that his work was known, for he had a secretive and shy personality, not unnaturally in view of the obstacles he tried in vain to overcome and the objections he



109 James Clerk Maxwell, the giant of nineteenth century physics, whose research paved the way for all forms of radio science.

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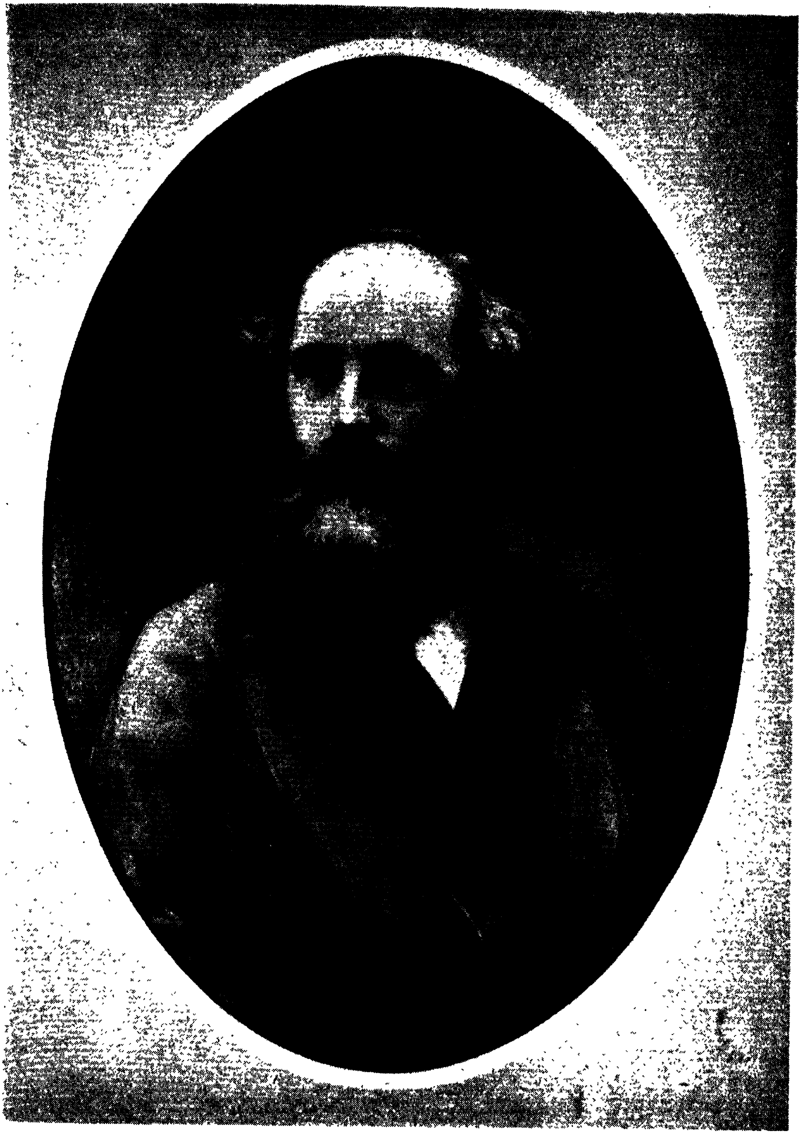

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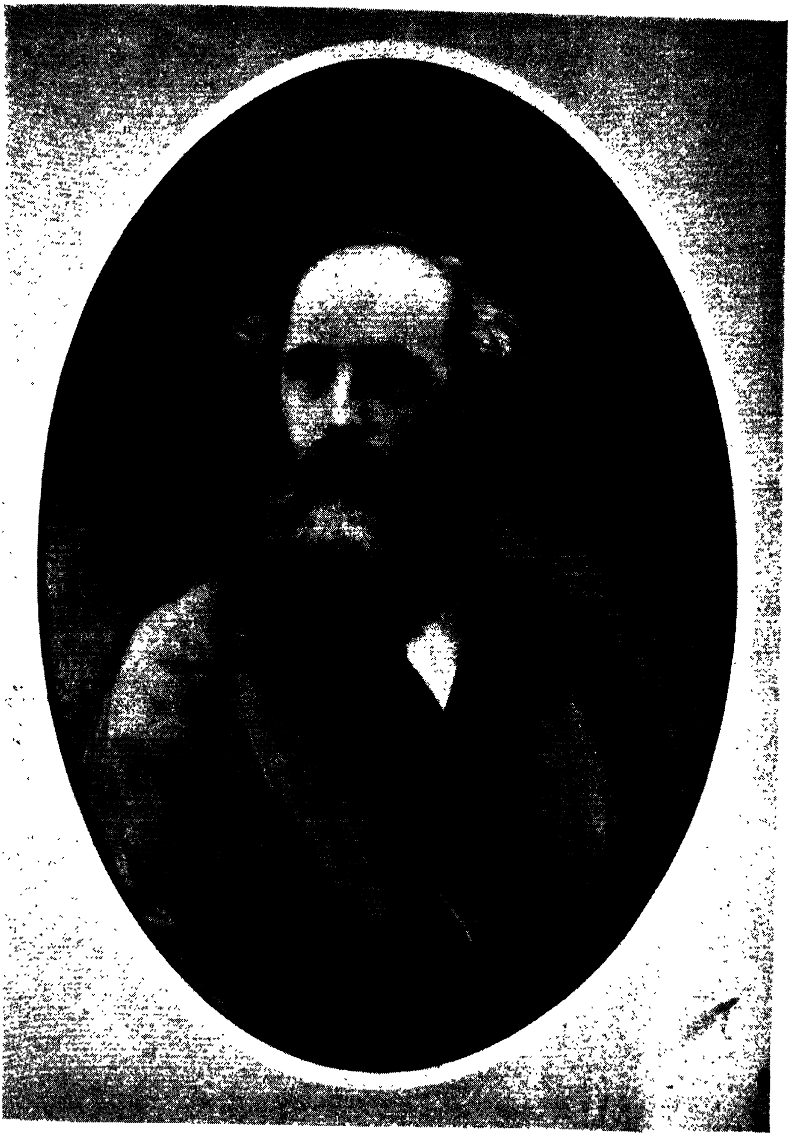

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met with from learned bodies. One invention of his was a microphone ; his accidental discovery was that the instrument would pick up the crackling of electrical machinery. He used a coil with a make-and-break effect in his workroom in Great Portland Street and walked about the street with his microphone picking up the crackling. Evidently the noise was very slight, as indeed it must have been, and a few of his friends who were persuaded to listen put the whole thing down to imagination. His precise methods are not known, for Hughes became embittered, refused to divulge any details of his apparatus, and remained in obstinate silence until his death in 1900.

By that time the name indissolubly linked with radio was becoming world-famous. It is, of course, Guglielmo Marconi. Britain can with justification claim at least a foster-parent's interest in this brilliant Italian. His mother was Annie Jameson, an Irish girl who had gone to Bologna in Italy to study singing and had there fallen in love with a wealthy Italian who lived at Pontecchio, near Bologna. Their son Guglielmo was born in 1874, and from early childhood was bilingual, an asset which enabled him to read scientific books in both English and Italian. His natural ability was fostered by the privileges of his family position, and his education was as fine as it was possible to make it. After attending exclusive private schools in Italy, he went to schools in Bedford and Rugby, and later to the universities of Bologna, Florence, and Leghorn. At the latter institutions he studied law, though not with any special intention of following that profession. As the heir to a large fortune and considerable estates, it was almost his duty to devote himself to family affairs. But scientific experiment attracted him more and more, and at his father's home he turned some rooms into laboratories.

His idea of sending messages through space first came to him, according to his own statement, in the spring of 1894 while reading a biography in an Italian electrical journal on Professor Hertz, who had died in January of that year. It seemed to him that an adaptation of Hertz's experimental apparatus in order to transmit short and long emissions corresponding

110 Mobile transmitter used in early experiments by Guglielmo Marconi (inset).

to the Morse alphabet was so simple and obvious that there was no particular advantage in following it up. He waited for some months to see what was being done, and when there was no news he himself began to experiment in December 1894. Before the year ended he had transmitted the first coherent message by radio-telegraphy. Within a few weeks he was achieving transmissions over a distance of a mile.

In the summer of 1896, the twenty-two-year-old Marconi sailed for England, where he knew that the Post Office was making advanced experiments in communication without wires under the direction of William Preece. As early as 1895 communication had been established by Post Office engineers between Crookhaven and the Fastnet Lighthouse under a system of non-continuous cable introduced by Willoughby Smith. Two wires were earthed, and the current changes on one were indicated on the other. In the same year wireless telegraphy by electro-magnetic induction was officially used during a temporary break in the cable between the Isle of Mull and the Scottish mainland.

The Post Office excelled itself in putting at the disposal of Marconi experimental facilities. Some of the earliest transmissions took place on the roof of the G.P.O. building in St. Martin's-le-Grand and later between that building and the Thames Embankment. Then Marconi moved to Salisbury Plain, where, under the shadow of Stonehenge, his apparatus must have aroused the envy and wonderment of the magician Merlin himself. In May, 1897, the crucial trials across the Bristol Channel were carried out, between a hill near Penarth and Brean Down, Weston-super-Mare, where, incidentally, the Admiralty's first heliograph signalling experiments had been made. Two months after signals had successfully been transmitted across nine miles of water, Marconi's patent rights were secured by an English company, and we have the most unusual example of an inventor still in his early twenties assured of financial and commercial success with his discoveries. At the head was a man with the appearance of a boy of eighteen. The first permanent radio telegraphy station was erected at Alum Bay, in the Isle of Wight.

111 Marconi in the room at Signal Hill, Newfoundland, where he heard the first wireless signal from England on 12 December, 1901.

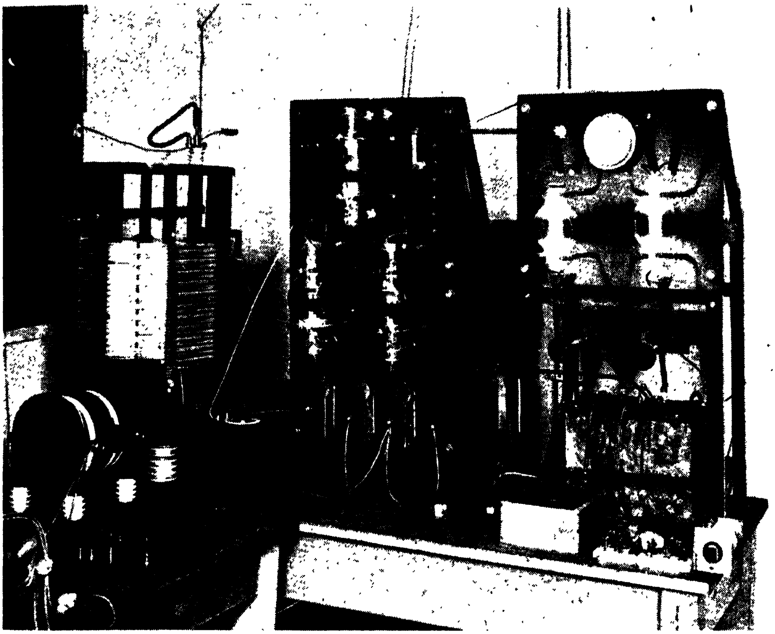
Progress was now both spectacular and fast. The first ship in motion to transmit a signal was an Italian battleship in 1897. In July 1898 radio-telegrams were sent from a vessel following the racing yachts at Kingstown Regatta and transmitted to the Dublin *Daily Express*, the first use of radio to speed up the transmission of news. On 28 March 1899, Marconi sent the first international message from the South Foreland Lighthouse to Wimereux, a little village (and once Napoleon's invasion base in his abortive plans to attack England) two miles north of Boulogne. Nation was speaking to nation.

Marconi was now ready to span the greatest obstacle of all, the Atlantic. While many scientists were busily penning articles to prove that reception over more than a few hundred miles was quite impossible, Marconi and his Post Office colleagues were building a transmitting station at Poldhu, Cornwall. Work began in October 1900. Marconi himself sailed for Newfoundland as soon as the transmitter was working. In December of the following year, in bitterly cold weather and half a gale, Marconi and his assistants attempted to fly some kites and a balloon. All were whirled away in the gale. Then they managed to get a kite with 400 feet of wire flying steadily. At a predetermined time Marconi sat in a rough little shed that had been built, and waited. Above the roar of the gale a faint and gentle buzz came through the headphones. The noises were repeated in groups of three over and over again. So, on 12 December 1901, the letter S marked the wireless linking of the Old World and the New.

Here was a triumph of invention which caught the public imagination. A world becoming accustomed to scientific marvels and to accept them quickly as a means of service made the expansion of wireless telegraphy a comparatively easy process for its protagonists. So far from being difficult to convince of the value of scientific magic, the blossoming twentieth-century citizen looked, accepted, and demanded more. He demanded the radio-telephone, and he had not long to wait.

Many engineers worked on the development, but the major step forward was the invention of the valve by Professor Ambrose Fleming. Born in Lancaster in 1849, Fleming had assisted Marconi in the construction of his early transmitters in England, particularly at Poldhu, and appreciated as much as any man the possibilities of this new communication system without wires.

Edison had noticed in 1883 some effects when experimenting with electric light bulbs which he could not fully explain, and about the same time Fleming published the results of similar investigations of his own. He correctly explained that any heated metal had the capacity of throwing out electrons from its surface—a sort of one-way traffic, in contrast to the normal two-way flow. By fixing a plate of metal inside an electric light bulb, he enabled the current to flow from the heated filament to the cooler plate, and in this way the vibrations at millions of times a second set up by radio waves could



112 Aerial tuning equipment (left), oscillator and modulating valves (centre), main power transformer and rectifying valves (right) of 2MT, the experimental broadcasting station at Writtle, Essex, which began transmissions in 1921.

be turned into mechanical vibrations of a much slower rate on the diaphragm of the headphones. The metal plate, charged with positive electricity, attracted the negative electrons streaming off the hot wire. This was the diode valve, a detector which transformed radio signals into speech. The American Lee Forest improved this device by interposing a grid between the plate and wire which magnified the weak changes in the impulses and so made amplification possible.

Early in 1913 the Marconi Company were conducting successful experiments in radio-telephony at Chelmsford. Then, with the First World War, experiments became shrouded in secrecy, though developments leaped ahead. With the return of peace, experiments were resumed in the open, and in 1919 a message was successfully transmitted from Ballybunion, Ireland, to Cape Breton, 1,800 miles distant.

Just a year later, in June 1920, the *Daily Mail* organised the first broadcast entertainment in Britain when Dame Nellie Melba sang from a studio in Chelmsford. In his book, *My Northcliffe Diary*, the then Editor of the newspaper, Tom Clarke, wrote:

> June 16, 1920: We had the Melba wireless concert last night. She went down to the Marconi place at Chelmsford. We had to arrange for a light supper for her of chicken and champagne. Soon after seven o'clock she started singing into a microphone hooked up with a 15-kw. set transmitting on 2,800 metres wave-length. I listened in at Blackfriars—frame aerial and telephones, not enough to go round. We listened in turns. Melba's girl secretary was there. Her eyes nearly came out of her head as she heard the nightingale voice in "Addio", from *La Bohème*. " It is Melba ! " she cried in astonishment. I think she had not believed us to that moment.
>
> . . . To-day we are receiving messages from all parts. All Europe was the audience last night. Messages from liners at sea tell us how passengers listened to Melba far across the water.

Broadcasting had arrived, though it was not until 1921 that an experimental station for a public service was licensed for operation. This was at the Marconi research station at Writtle, near Chelmsford, where Captain P. P. Eckersley, who afterwards became Chief Engineer of the B.B.C., started a service of half an hour once a week. Elsewhere broadcasting was beginning and a great new industry serving a new form of entertainment sprang into existence.

Marconi died on 19 July 1937. With truth, one obituary called it the forty-third year of the Radio Age, for it was just that period since the first intelligible signals had crossed the dining-room table in the home of the Marconi family at Bologna, Italy.

27

TRANSMISSION OF SHADOWS

THE INVENTORS OF TELEVISION

WIRELESS telegraphy was the means of providing a vital clue to the solution of the problem of transmitting vision. One summer's afternoon in 1873 a young telegraphist named Joseph May sat basking in the warmth from the sunshine which streamed through the window of a signals office. The place was Valencia, Ireland, the European terminus of the transatlantic cable. May noticed an unfamiliar hum coming from the receiver and he leaned forward to see what was wrong. As his hand passed over a resistance coil the hum changed to its usual note. He moved his hand backwards and forwards, now near the coil, now some feet away. The hum obediently changed its tone. Looking at the telegraph indicator needles, he saw that they too moved slightly. He deduced that the shaft of sunlight was the cause and also that light, not heat, was responsible for slightly affecting the current passing through the selenium-covered coil.

May put through a routine report which eventually came to the attention of the scientists on both sides of the Atlantic. Immediately scores of them began to investigate the metal which had the property of converting light values into electric values. Many of them hoped that, by a reverse process, light could be made to produce current—a delightful situation in which a shaft of sunshine would send electric motors spinning steadily. Others visualised an electric picture to be transmitted along a wire just like the " electric telephone ". They did not think of breaking the picture up and transmitting it piece by piece, and in any event there was the insuperable difficulty of amplifying the very weak current passed by the selenium, for the radio valve had not, of course, been invented at that time.

Ten years later a German, Paul Nipkow, invented a whirling metal disc pierced with holes that allowed a focusing lens to scan an image and break it up into tiny fragments. The variations of tone could then be picked up by photo-electric cells, transmitted along a wire, and converted to light and shade by a neon tube projecting the rays through another revolving disc and a lens. This was the ultimate goal of mechanical television, and visualised by the pioneers of the late nineteenth century. For more than twenty years the possibility of transmitting pictures remained a theory. The man who was to achieve it was born four years after Nipkow invented his disc. His name was John Logie Baird.

The son of a minister of the Church at Helensburgh, Dumbartonshire, John Baird was a weakly child. Because of long absences from school through chest and heart trouble, his career was quite undistinguished, though everyone in Argyll Street, where the Baird family lived, had cause to remember him. Scientific experiments connected with bicycles, photography, and telephones kept the youths of the district busy at week-ends and aroused the misgivings of their parents. Wires criss-crossed the road so that young Baird and his friends could converse with one another from their bedrooms. Electric lights glowed dimly, flickered, and expired when the home-made generating plant broke down. Baird's father, who had hoped his son would follow in his footsteps and enter the Church, realised that engineering was his calling if he could retain such health as he had, which seemed doubtful.

Baird went to the Glasgow Technical College for a course of electrical engineering and from there to Glasgow University. Shortly after his training was completed, the First World War broke out. Baird promptly volunteered and was as promptly rejected. He then obtained an executive post with the Clyde Valley Electric Power Company. As soon as his day's work was over, he used to experiment on television. His results seemed so promising to him that in 1919 he took the bold, and maybe foolhardy, step of resigning from his job. He had very little money, and to obtain sufficient to eat and to buy equipment he invented a number of gadgets which he sold to

Glasgow shopkeepers. When his health showed signs of giving serious trouble, he went for a time to the West Indies. He carried on a variety of small businesses there with no great success, and the main objective—better health—eluded him. By 1921 he was back in England, and for a few months he had quite a successful soap business. This terminated abruptly when he became seriously ill. His friends persuaded him to go to the sea, where, in their unspoken opinion, he could live out the few remaining months of his life in peace and comparative comfort.

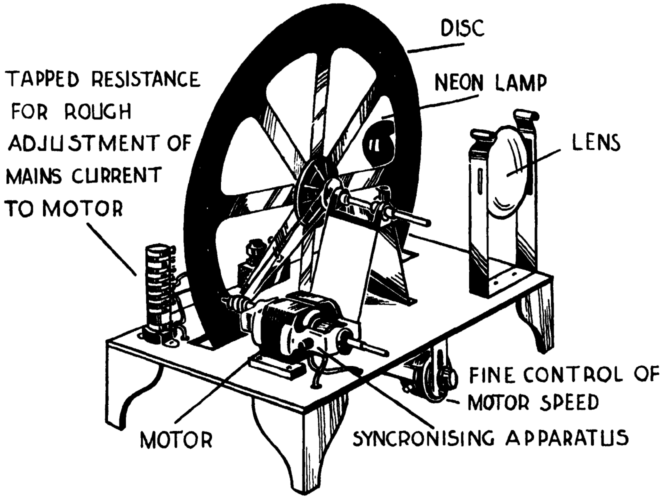
The place he chose was Hastings. Not one holiday-maker in a thousand ever sees the pathetically modest little tablet which can be found in a shopping arcade in that town marking the birthplace of television. We are a strange people, and our modesty about our citizens who deserve some mark of appreciation is exasperating, particularly to overseas visitors, who usually know more about them than we do. During the war, the writer was approached by an American officer strolling about near the clock tower in the centre of Hastings, who in a resigned voice asked where Baird's workshop was. "It's the place where he invented television," he explained. The place was just fifty yards from where he was standing. The officer, who in civilian life was an executive of a Californian radio station, and then an Army radar expert, had travelled from Dorset to see the birthplace of television, which he knew was somewhere in Hastings. He had asked eight people, including a policeman, a postman, and Civil Defence officials. None knew anything about it.

But the room in Queen's Arcade is deserving of better fame though the environment is not inspiring. It was the cheapest Baird could find. He spent much of his time sitting on the front, climbing painfully up Castle Hill, and reading in the nearby municipal reference library. Slowly he assembled the equipment he needed. One day he bought a tea chest at a grocer's and carried it to his attic, where it became a motor housing. On the washstand a biscuit tin housed the projection lamp. Bits of ex-Government wireless equipment were picked up after careful searching through the trays outside junk stores; lenses at 4*d.* each came from second-hand shops. The scanning discs were cut out of old cardboard, and the whole device was mounted on scraps of wood and held together by glue, pins, and sealing-wax.

This was the equipment which enabled Baird to beat some of the greatest commercial concerns of the world in the race for the transmission of light and shadow by electrical means. In that rather shoddy room at Hastings Maltese crosses and letters of the alphabet were transmitted over a few feet of cable, and later by wireless, to be produced in shadowy silhouette by a whirling disc.

Baird had an excitable, friendly character, and he was not diffident about letting the Press know what he was doing. Garbled accounts of the experiments appeared from which the public did at least gain knowledge that something remarkable was in its birth-throes, even though not even the most optimistic reporter could pretend it had much entertainment or utilitarian quality. However, the news brought financial help to the struggling Scotsman. He formed a company, packed up his equipment in a few crates, and returned to London, where he rented an attic flat in Frith Street, Soho. The nine days' wonder of Hastings died away from the columns of the Press and Baird returned to the monotonous work of trial-and-error which was his method. He had neither the training nor the temperament for paper work. Such plans as he made or circuits he designed were scribbled on the wall. "Build, test, tear down, and build again" was his maxim. One day Gordon Selfridge, Junior, son of the founder of the Oxford Street store, walked up the stairs to the Baird flat to see for himself what Baird was doing. He was so impressed that he suggested a three weeks' demonstration at the store. Baird eagerly agreed, partly because he badly needed the £75 fee and also for the publicity the demonstration would provide. It took place in April 1925—"something", as Messrs. Selfridge said, "that should rank with the greatest inventions of the century".

Many thousands saw the silhouette of a face—and most of them regarded the whole business as a rather complicated form of toy. It was all forgotten very quickly. By the end of the summer Baird's resources had almost disappeared. In


DISC
NEON LAMP
TAPPED RESISTANCE FOR ROUGH ADJUSTMENT OF MAINS CURRENT TO MOTOR
LENS
FINE CONTROL OF MOTOR SPEED
MOTOR
SYNCRONISING APPARATUS

113 Drawing of the receiver used for the Baird 30-line television transmissions by the B.B.C. from 1932–35.

order to pay the rent, he confined his meals to coffee and rolls in the small cafés of Old Compton Street. Eventually he was without means and he was compelled to ask his family for help. It was forthcoming. Another company was formed and once more Baird worked with that single-minded purpose which was his main strength. His aim was, of course, to reproduce an image with light and shade as well as outline.

He reached his goal accidentally, as he himself subsequently said :

> One day, the fifth Friday in October [1925] I experienced the one great thrill which research work has brought me. The head of the ventriloquist's doll which I used suddenly showed up on the screen as a real image with details and gradations of light and shade.

Excited, Baird ran downstairs and asked an office boy named Bill Taynton if he would like to earn half a crown. The youth agreed and was placed under a bank of lights while

Baird ran into the adjoining room, where he had his receiver. The boy's face was clearly seen—the first human being to be televised.

In the following January Baird invited the members of the Royal Society to see a demonstration. They trooped up the stairs six at a time and watched one another by television. On that night of 27 January 1926 Baird's reputation, not to mention his financial security, was assured by the opinion of one of the greatest scientific bodies in the world.

Baird moved into larger offices, and was almost immediately plunged into a contest which he loved. America had, independently, reached Baird's goal only a few weeks after him, and various companies indulged in all sorts of feats of transmitting over long-distance telephone cables in order to bring television to the attention of the public. Baird simply beat them at their own game. Pictures were transmitted between London and Glasgow in May 1927, and in the following January he spanned the Atlantic, his own head as he sat in a Long Acre, London, studio being seen, albeit a trifle distorted and blurred, in a suburb of New York. This feat was described by the *New York Times* as deserving of comparison with Marconi's transmission of the letter S across the Atlantic.

Experimental broadcasts by the B.B.C. of the Baird television system began on 30 September 1929. They lasted until 11 September 1935, when the last programme was given. One reason for the cessation was that the thirty-line mechanical system did not give a sufficiently high quality of reception to maintain interest. Another was that in the laboratories of both Britain and America electronic television was ready for use. In the U.S.A. Dr. Vladimar Zworykin had patented the iconoscope as early as 1923, and had been working on electronic television ever since then, while in Britain the E.M.I. organisation at Hayes, Middlesex, was working hard on research, under the direction of Alan Blumlein and Dr. J. D. McGee, two men whose work resulted in the television system of post-war Britain.

The device which was being used to eradicate the mechanical inefficiences of television transmission and reception, with all

114 William Crookes, who succeeded in deflecting the rays in a cathode tube.

their time-lag and errors of movement, was the cathode ray tube, an instrument capable of infinitely quick and accurate reaction to electrical impulses.

To-day it is a truism to say that the heart of the television receiver is the cathode ray tube, yet few people understand its method of operation or know the story of development which lies behind this rather fearsome piece of apparatus. Although it was the demand of radar stations during the war which brought performance of the cathode ray tube to its present pitch of efficiency, the electrical phenomenon which it controls was known nearly ninety years ago. The name " cathode rays " was given by a German scientist named Goldstein, when they were noted by him and a group of colleagues experimenting with the effects of passing electric currents through a vacuum. This was the era when all sorts of tests were made to produce sparks across gaps, and when the same idea was tried out with the gap inside a vacuum it was seen that quite different things happened—there were blobs of light on the surface of the glass of the container, for instance. Faraday first reported that when gas pressures were very low these light effects tended to move towards the anode, leaving a patch of darkness just in front of the cathode at the other end. This was duly called " the Faraday space ".

Some ten years later a scientist named Hittorf proved that the phosphorescent glow on the glass was due to some kind of matter which travelled in a straight line, no matter where the anode might be, and he also showed that it could be cut off by placing obstacles in the way. But, apart from showing what could be done, he made no attempt to explain it all. That was left to a British scientist, William Crookes. He dismissed the suggestion that the mysterious cathode rays were light rays and believed that they were electrical particles shot off at tremendous speed by the electrical forces. He also succeeded in deflecting the rays to any part of the cathode end by means of a magnet. This, as anyone with a television receiver will realise, was fundamentally the first crude version of the " heart of the television receiver ". But to-day's users would not recognise the tube Crookes used as such. It was only 1 foot long and of a weird shape where he left room for his mica screen and the aluminium electrodes. Up to the turn of the nineteenth century these cathode ray tubes were made in the scientists' laboratories, but in 1902 the first commercial tube was produced in a small City workshop owned by A. C. Cossor. It was a bizarre device, rather like an old type motor horn in glass, with various little branches for the electrical equipment.

Official investigation into television technique suggested that high definition was essential for a regular service of any entertainment value. On 2 November 1936 Baird saw a twenty-year-old dream come true when the world's first regular public television was inaugurated. But there was bitter disappointment as well. The B.B.C. were using two inventions alternately—the Baird 240-line system and the E.M.I. 405-line method. Baird's system used mechanical scanning equipment which was a triumph of precision engineering.

But no skill or mechanical exactitude could compare with the performance of the E.M.I. electron scanners, and everyone knew, though they could not bring themselves to say it, that Baird was beaten at the post. Too late he switched to the perfection of an electron camera himself. The race was over. The E.M.I. pictures were unrivalled.

Baird soon suffered yet another blow. One February night in 1937 all the experimental equipment owned by his company was destroyed in the fire at the Crystal Palace, where he had set up an experimental station. He was now a fairly wealthy man and might have been content to draw a good income from the firm bearing his name, which was making receivers, and to nurse his health. But the inventive genius still prodded him on, and he continued work on colour and stereoscopic television.

On 16 August 1944, in his laboratory in Sydenham, he demonstrated a colour system which used two cathode ray tubes, one giving a green picture and the other a red one. Two colours only (as such systems have proved in the cinema) are not really satisfactory. Three are needed. Nevertheless, this demonstration, given while the flying-bomb attack on London was at its height, was probably the first all-electronic colour television ever achieved.

Baird died at Bexhill, not very far from the scene of his first triumph, after some months of illness on 14 June 1946, just one week after the B.B.C.'s television station, closed since 1 September 1939, began transmissions again. He lived long enough to know that television was a major technical—and social—event of the age, an invention creating a huge industry in its own right, and giving employment to tens of thousands as well as pleasure to millions in the principal countries of the world, with millions of pounds of capital involved. The man who had done more than anyone to create this industry left assets of only £7,000.

28

THE MAGIC EYE

THE DEVELOPMENT OF RADAR

THE natural phenomenon of radio waves travelling round the world instead of shooting off into space was the subject of a study which eventually gave birth to the invention of radar, a British triumph of war operations which has since become an invaluable asset in peace. At first scientists put forward theories which ranged from the just possible to the bizarre to account for the path of radio waves. The true explanation came from Oliver Heaviside, who suggested that there were " mirrors " in the sky. Heaviside was a " character " in the popular sense of the word. Born in 1850, he became a brilliant telegraph engineer, but had to retire at the age of twenty-four because of deafness. Thereafter he lived the life of an eccentric recluse at Torquay, but from his pen came theories on radio and long-distance telephony problems which were a major contribution to science. Independently, A. E. Kennelly, an American professor of English descent, also propounded the " mirror " theory—which is now known as the Kennelly-Heaviside layer.

Although mathematical evidence was forthcoming to prove the existence of the " mirror ", science demanded proof, and until it was forthcoming a dispute about the layer's existence and form continued intermittently for some twenty years. Then, in 1924, Professor E. V. Appleton, a research worker in the Cavendish Laboratory at Cambridge, determined to prove that the layer was there.

He requested a branch of the Department of Scientific and Industrial Research, known as the Radio Research Board, to provide facilities. With these he quickly achieved spectacular success. He took his receiving equipment to Oxford in the summer of 1924 and enlisted the services of the B.B.C. The engineers of the Bournemouth station, which then existed for the South Coast service, used to start work as soon as the evening programme finished. What they did was to vary the wavelength of 386.5 metres through ten metres on either side. Appleton sat in his workroom at Oxford and listened. As he had surmised, he obtained alternate periods of strong and weak reception as the wavelength wobbled. From the change in wavelength between one peak of loud reception and the next he could calculate the lengths of the two routes the radio waves were taking—one direct from Bournemouth to Oxford and the other from Bournemouth, up into the sky, and down again. The time difference was, of course, very small as radio waves travel at 186,000 miles per second, but the " interference " which the waves arriving after different distances of travel produced gave a calculable effect. The length of the longer path was then a matter of very simple geometrical calculation. Appleton was able to announce that the Kennelly-Heaviside layer hung in the sky some seventy miles above the earth, and it was this mirror, continually reflecting radio waves down again, that made long-distance reception of broadcasting frequencies possible.

From the summer of 1924 the Heaviside layer was regularly watched. A special transmitter was erected at the National Physical Laboratory at Teddington, the Post Office loaned another at Peterborough, and reception points were set up at Cambridge and in London, where Professor Appleton was then working at King's College. Day and night the radio watch went on, and it was soon discovered that the layer rose and sank like a vast stretch of silk billowing in a breeze—though each wave often took twelve hours, the sun's rays evidently being responsible for lowering the layer. Professor Appleton himself always worked on Saturday or Sunday nights—partly because he then had the time for an all-night vigil and also on account of the lack of interference from trams on the Victoria Embankment and traffic in the Strand. One such Sunday morning he found that at 5 a.m. the radio waves were not coming in from a seventy-five-mile trip from the layer, but from more than 150 miles into space. The jump was sudden. Despite the easy suggestions that this was merely a case of waves making more than one journey, Professor Appleton obstinately put forward a belief that the Heaviside layer had weakened, let the waves through, and these had then shot upwards until another and hitherto unsuspected layer sent them down again.

Now something was needed to time the thousandths of a second's difference in the three possible signals received—the direct one, the wave that went a round trip of 140 miles, and that which managed to get through the Heaviside layer and journeyed some 300 miles. It needed a transmitter which sent out pulses, a simple analogy being the smoke rings which a smoker can make instead of the usual stream of exhaled smoke (which is the normal radio transmitting method). Each pulse may last one ten-thousandth of a second, but before the next one starts on its journey the first is about twenty miles away, being issued at one-fiftieth of a second intervals. Portraying the results of the pulses is the job of the cathode ray oscillograph. A spot of light travels across the tube just as quickly as the transmitter issues pulses. A signal received at a steady interval of time will then make a small blip or dagger in the band of light, but if one wave takes longer to arrive, then another blip will appear at a different place. Such, basically, was the system set up between transmitters in East London College and King's College, Strand. The cathode ray oscillograph faithfully showed the blips of waves travelling by three different paths—one the ground wave, another by the Heaviside route, and a third which had soared to the Appleton layer and back. The existence and position of the layers were proved—and, more important from an industrial viewpoint, radar had been invented, though this was not realised at the time.

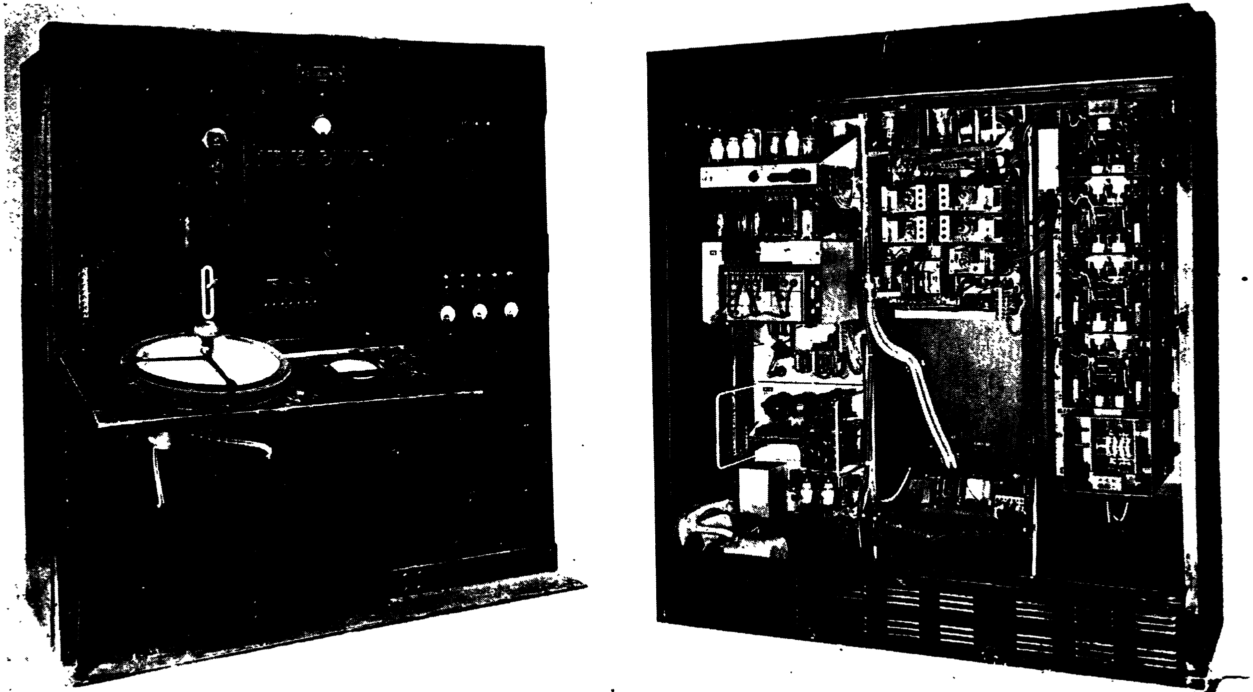
How a ready-made invention was adapted for practical use is one of the most remarkable stories of British science. One account, which was regularly told to trainees on radar in the R.A.F. during the war, of whom the writer was one, was that the radio echo from an aircraft was recognised in the early stages of the Appleton experiments. It was said that one of the scientists in the Cambridge area co-operating on the tests complained to a nearby R.A.F. station about aircraft which interfered with the experiments, reflecting echoes which should have come from the Heaviside layer. Neither the complaining scientist nor the R.A.F. station commander who was asked to send his aircraft elsewhere realised the significance of what was happening. Such is the story, but one doubts its veracity. What is certain, however, is that Post Office engineers supplied the material for a minute in a file written in 1931 which referred to the interference effects that occurred whenever aircraft flew within four miles or so of the commercial short-wave stations.

Radar was, of course, first of all a war weapon. It was born because the Press and public of Britain demanded some magic means of safeguarding these islands from air aggression. The easiest thing, according to the laymen who wrote and spoke so glibly, was to invent a death ray. The Government duly enquired of science whether some form of ray which would upset an aircraft engine was possible. The man who was told to prepare a report was named Robert Watson-Watt. As far back as 1916 he had been locating atmospheric storms by means of radio at a special research station built at Farnborough. The aim was to find out why these storms interfered with radio reception and also to try to locate them at a distance so that airmen could be warned of their approach. Eventually it was possible to photograph the wave-shape, locate the position, and plot the path of atmospheric storms, this being the work of the Radio Research Board formed under the superintendence of Watson-Watt in 1920. As about 100 lightning flashes a second occur perpetually somewhere around the globe, a very fast system of recording them was needed, and for this the ubiquitous cathode ray oscillograph was pressed into service.

So Watson-Watt, given the task of explaining that sufficient energy to short-circuit an aeroplane engine or affect the physique of the pilot could not be transmitted by any known method, added a note referring to his own experiments on the detection of storms and the system used by Professor Appleton and his colleagues for scientific investigation of the layers. Calculations, worked out in thirty minutes by Watson-Watt's colleague at the National Physical Laboratory's Radio Department, A. F. Wilkins, were also incorporated to show that detection of the presence of aircraft by radio methods seemed a promising substitute for the death ray which the politicians and defence chiefs desired.

Britain lives as a free nation to-day because this note was instantly acted upon. The report was read to a committee of research on air defence under the chairmanship of Mr. H. T. (later Sir Henry) Tizzard on 28 January 1935. Less than a month later a van halted ten miles from the stunted aerials of the Empire short-wave broadcasting service of the B.B.C. at Daventry. Overhead an aircraft circled and circled on a route which seemed without reason to the pilot, for he had not been told the object of it. The next day ("27 February 1935 is a vital date," Sir Robert Watson-Watt stated in 1951) a report stated that the men inside the van had " seen " the aircraft and estimated, by the reflection of the radio waves, that the machine was eight miles away.

The rest of the story has been told as one of the major feats of Britain's effort in the Second World War. A laboratory was built at Orfordness, the most easterly point of England on the Suffolk coast, and work began on 13 May. That summer only the distance of an aircraft from the station could be found. From a theory which Watson-Watt jotted down in the train from Liverpool Street one week-end a method of ascertaining the bearing was perfected. By January 1936, when a new station had been opened at Bawdsey near Felixstowe, the scientists were watching the coming and going of the air liners between Holland, Germany, and England. They knew far more about the flights than the controllers at the airports. R.A.F. pilots who interrupted their training flights and nipped down for a quick drink at a neighbouring aerodrome were dumbfounded when the Commanding Officer seemed to have the psychic powers necessary for knowing all about the when and where of their journeyings through the sky.



115 Front and interior views of the early radar receivers constructed for the British Government and installed on the coast during 1936–39.

"With the basic invention complete, the problem was then one of production and improvement. In this the leading firms of the radio industry achieved miracles before war broke out and even greater miracles afterwards. When peace came a great new industry was ready to go into service for the benefit of mankind.

To-day the primary use of radar equipment is in air and sea navigation. The Cossor Company, makers of the first radar receivers,[1] carried out prolonged tests on marine radar apparatus with astonishing results as soon as the war was over. One of the first trials was made in December 1945, when a small steamer, the *Atlantic Coast*, made the run from London to Liverpool by radar navigation. The weather co-operated, supplying everything from sleet to dense fog. But the ship's master, Captain Edward Griffiths, had no worries. On the glowing screen of his cathode ray plan position indicator he could see every island, rock, lightship, buoy and passing vessel within a ten-mile radius. Said Captain Griffiths : " It is the greatest boon the shipmaster has ever had. It means the end of fog collisions at sea."

With the efficiency of marine radar proved, work went ahead on other vessels. The *Queen Elizabeth*, for instance, has the finest radar equipment in the world, the installation of which was preceded by months of careful testing. A complete duplicate installation was built on top of a Highbury factory for experimental purposes, at the height of the ship's bridge above water-level.

Apart from the fact that the revolving beam of the radar-scanner picked up Battersea Power Station, the dome of St. Paul's, and the buses on the No. 19 route along Highbury Grove, instead of the cliffs, ships and wharves for which it was planned, the test gave exact working conditions. By the end of 1950 more than a thousand British vessels were equipped with " magic eyes ".

Radar can take care of over 80,000 tons of steel and machinery in the shape of the *Queen Elizabeth* : it will do the same for blind people. By covering bats' eyes, mouth, and ears in turn, scientists have proved that ears and mouth were necessary for their unerring night flight. They concluded that the bats emit some sound which is reflected back to them well above the range of the human ear. This is a natural form of radar, and apparatus for blind people will have to imitate the procedure : as soon as an obstacle appears within a predetermined range, the echo will return and emit a warning note so that evasive action can be taken.

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[1] The first radar transmitters—the groups of masts that began to appear in eastern England during the 1930's, causing so much speculation among the local people when their actual purpose was still a closely guarded secret—were built by Metropolitan Vickers, Ltd.

The same basic idea is being actively developed by British railway engineers. It is known as sonar, radar's supersonic cousin, and for use in fog or at night will provide a certain guide for the driver. Sonar-equipped engines will send out whistle blasts at a frequency above the 30,000 cycles a second which no human can hear. Any signal at danger or any obstruction on the line will reflect the sound waves to the engine cab, where a light will flash or a bell ring.

Map-makers are busy with radar too. Impossible terrain in tropical and mountain areas can be charted with the "Oboe" radar beam. This was discovered accidentally when aircraft patrolling the North African desert during the war picked up indications of ground masses on their ground-searching radar screens. The aircrews thought they were troop or transport concentrations, but actually they were rock formations 5 or 10 feet below the surface of the sand.

For the astronomer, radar offers incalculable possibilities. By using a radar telescope, scientists have mapped a universe of stars 750,000 light-years distant. Invisible to any ordinary telescope, the emission from some of these stars detected by the radar telescope began their journey when animal life was only beginning on the earth. Radar has looked into the very heart of the sun and enabled science to measure its heat—1,000 million degrees.

The use of radar in the air transport industry is vital. Radar is overcoming all the weather problems that are prone to wreck airline schedules. Airfield controllers have a complete picture of their runways in fog or darkness, in addition to a chart of the sky around their fields. For the pilot there is a white line track laid across the sky, automatic landing assistance, a picture of the ground over which he is flying, and a chart of all other aircraft and sky obstructions in his vicinity. On tropical routes special radar gives full details of cloud formations—all adding up to a greater safety in flying.

From a super-secret war weapon, radar has become one of the greatest of modern industries. Offspring of radio, this vigorous youngster now gives work to almost as many people as its parents.

EPILOGUE

THIS book has been but a brief chapter in the story of man's material progress. The contribution of Great Britain to the world's present standards of life during the Industrial Revolution was formidable. Even though the stress has intentionally been on this nation's invention and industry, it is hoped that no suggestion has been given that the British people were blessed with supra-natural gifts of genius. Their pre-eminence came rather from a fortunate combination of circumstances of economic strength, the necessary natural resources, a tenacious obstinacy in overcoming problems, and freedom for the individual to think and experiment.

It has truly been said that every invention has a pedigree. He would be a bold and ill-advised man who claimed that Watt was the sole inventor of the steam engine or Whittle of the jet. Faraday finalised experiments with electricity which had been conducted for 1,000 years and more. Stephenson was one of several locomotive-builders. An attempt has been made to describe the work and character of men who are famous and to give recognition to some of the lesser-known inventors in those industries where Great Britain led world progress. Even so, many men go unrecognised and unmentioned in these pages, as they always have. They are the unhonoured and sometimes unknown men who committed the unforgivable sin of being born before their time. The accent has therefore been on the practical values of invention. Those who merely invented are legion. Those who both invented and grasped opportunity are the select few.

If the Britain of the Industrial Revolution has a claim to mankind's gratitude, it is because she was the land of opportunity. Old ideas were revived ; men with new ideas came to her shores; brains were an asset. And behind the business-man ready to try out new ideas were the British craftsmen. The triple combination of inventor-promoter-worker overcame all obstacles, and by its close-knit energy a tremendous change in man's way of life occurred. The leading characters in this exciting picture have, it is hoped, duly been portrayed. The detail, of equal interest, needs a far broader canvas than a single book, and fortunately there is a vast amount of literature for the benefit of those who wish to make a special study of some facet of the subject. If such an interest has been engendered by these pages, then one purpose of the author has been served.

BIBLIOGRAPHY

THE literature of British industry and invention is large. Of the many scores of books and reference papers which have been consulted by the author, the following proved of particular interest and can be recommended for further reading:

POWER

Agriculture

Agricultural Research, Rothamsted. Sir John Russell. (Longmans, Green, 1946.)
English Farming Past and Present. Lord Ernle. (Longmans, 1936.)
English Husbandry. R. Trow-Smith. (Faber, 1951.)
Rural Rides. William Cobbett. (Everyman Edition, Dent.)

Coal

Coal—and All About It. Dorothy Howard Rowlands. (Harrap, 1946.)
Rise of the British Coal Industry (2 vols.). J. U. Nef. (Routledge, 1932.)

Electricity

Electric Illumination. W. T. O'Dea. (H.M.S.O., 1947.)
Sir Joseph Swan. Kenneth R. Swan. (Longmans, 1946.)

MACHINE TOOLS

Sir Joseph Whitworth. Professor F. C. Lea. (Longmans, 1946.)

NUCLEAR FISSION

General Account of the Development of Methods of Using Atomic Energy for Military Purposes. (U.S. Government.)
Science at War. J. G. Crowther and R. Whiddington. (H.M.S.O., 1947.)

STEAM

James Watt. H. W. Dickinson. (Cambridge University Press, 1936.)
James Watt and the Industrial Revolution. H. W. Dickinson and H. P. Vowles. (Longmans, 1946.)

MANUFACTURES

CERAMICS

English Country Pottery. Reginald Haggar. (Phoenix House, 1950.)

CHEMISTRY

Chemistry. A. Barclay. (H.M.S.O., 1937.)
The Great Chemists. E. J. Holmyard. (Methuen, 1928.)
History of Chemistry. F. J. Moore. (McGraw-Hill, 1918.)
Origins and Development of Applied Chemistry. J. R. Partington. (Longmans, 1935.)
Plastics. Dr. N. J. L. Megson. (Longmans, 1946.)
A Short History of Physics. H. Buckley. (Methuen, 1927.)

METALS

Iron and Steel in the Industrial Revolution. T. S. Ashton. (Manchester University Press, 1924.)
Metals in the Service of Mankind. (Institution of Metallurgists, 1950.)
Steelmakers. Harry Brearley. (Longmans, 1933.)

TEXTILES

The Cotton Trade and Industrial Lancashire. A. P. Wadsworth and J. L. Mann. (Manchester University Press, 1931.)
The Yorkshire Woollen and Worsted Industries. H. Heaton. (Clarendon Press, 1920.)

TRANSPORT

AVIATION

Aeronautics : Interpretative History of Flight. M. J. B. DAVY. (H.M.S.O., 1948.)
The Aircraft Builders. (H.M.S.O., 1947.)

INLAND TRANSPORT

A Hundred Years of Inland Transport. C. E. R. SHERRINGTON. (Duckworth, 1934.)
Land Transport. E. A. FORWARD. (H.M.S.O., 1931.)
Mechanical Road Vehicles. E. A. FORWARD. (H.M.S.O., 1936.)
The Story of Telford. SIR A. GIBBS. (Maclehose, 1935.)
The Story of the Road. J. W. GREGORY. (Maclehose, 1931.)

SEA TRANSPORT

British Shipping. R. H. THORNTON. (Cambridge University Press, 1945.)
Down to the Sea. G. BLAKE. (Collins, 1937.)
Merchant Steamers and Motor Ships. H. P. SPRATT. (H.M.S.O., 1936.)
The Steam Turbine and Other Inventions of Sir Charles Parsons. R. H. PARSONS. (Longmans, 1946.)

COMMUNICATIONS

ILLUMINATION

Darkness into Daylight. W. T. O'DEA. (H.M.S.O., 1948.)
(*See also under* POWER.)

PHOTOGRAPHY AND CINEMATOGRAPHY

History of the British Film. RACHEL LOW and ROGER MANVELL. (Allen and Unwin, 1948.)
Miracle of the Movies. LESLIE WOOD. (Burke, 1947.)

RADAR

Radar. (H.M.S.O. reprint of U.S. official publication, 1946.)

RADIO AND TELEVISION

B.B.C. Year Books. (1934 onwards.)
Radio Communication. W. T. O'DEA. (H.M.S.O., 1934.)
Radio Round the World. A. W. HASLETT. (Cambridge University Press, 1934.)

GENERAL

British Engineering Societies. L. St. L. Pendred. (Longmans, 1946.) An account of the valuable contribution of technical groups.

British Scientists of the Nineteenth Century. J. G. Crowther. (Kegan Paul, 1935.) Vivid and factual biographies of leading personalities in their field.

A Century of Science. Ed. Herbert Dingle. (Hutchinson, 1951.) A comprehensive survey of the later stages of the Industrial Revolution.

The Century of Science. F. Sherwood Taylor. (Heinemann, 1941.) A most readable account of nineteenth century progress.

A Century of Technology. Ed. Percy Dunsheath. (Hutchinson, 1951.) To be read in conjunction with *A Century of Science.*

The Common People. G. D. H. Cole and Raymond Postgate. (Methuen, 1938.) A classic on the economic and social effects of the Industrial Revolution.

Economic History of Modern Britain (3 vols.). J. H. Clapham. (Cambridge University Press, 1938.) For the serious study of this country's place in the world.

English Social History. G. M. Trevelyan. (Longmans, 1944.) The most authoritative—and most readable—work of its kind.

The Gild Merchant. C. Cross. (Clarendon Press, 1890.) An interesting account of the traditions behind British industry.

Great Men of Science. Philipp Lenard. (Bell, 1938.) Detailed biographies of both British and foreign scientists.

Industrial Biography. Samuel Smiles. (John Murray, 1879.) Rather long-winded but interesting accounts of notable inventors.

The Industrial Revolution. T. S. Ashton. (Oxford University Press, 1948.) A most readable survey of the political and economic effects.

Journal of the Royal Society of Arts. Lectures and papers by leaders of every industry.

Life and Labour in the Nineteenth Century. C. R. Fay. (Cambridge University Press, 1920.) An excellent book for a general picture of life a century ago.

Lives of the Engineers (5 vols.). SAMUEL SMILES. (John Murray, 1862.) To be read in conjunction with *Industrial Biography.*

Men, Machines and History. S. LILLEY. (Cobbett Press, 1948.) The entire field of human invention from the dawn of history analysed, described and tabulated.

The Rise of Modern Industry. J. L. and B. HAMMOND. (Longmans, 1925.) Of value to the student of economics.

Science for the Citizen. L. HOGBEN. (Allen and Unwin, 1938.) A first-rate technical book written for ordinary folk.

Science since 1500. H. T. PLEDGE. (H.M.S.O., 1939.) A world-wide survey for the technically-minded.

Scientists and Amateurs. DOROTHY STIMSON. (Sigma, 1949.) The contribution of the Royal Society to science.

Transactions of the Newcomen Society. Valuable reports on inventions and engineering.

The World's Wealth. W. G. MOORE. (Pelican, 1947.) A survey of raw materials.

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